# Suspended Sediment Transport Analysis and Water Quality Characterization Studies in Agricultural Rivers

（農村地域の河川における懸濁物質の輸送解析と水質特性に関する研究）

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# ABSTRACT

Suspended sediment is one of the major pollutants in streams and has been described as the most abundant. It is the most visible pollutant originating from agricultural areas, both point and non-point sources, and is caused by natural and accelerated erosion from land surfaces and stream channels. Agricultural activities cause much of the accelerated erosion due to unfavourable and poor tillage practices. Suspended sediment is an important water quality to be monitored and estimated in rivers, and an important input in watershed water quality management. Likewise, it is an important problem to be addressed, especially in areas with high agricultural activities and erosion rates.

For rivers draining agricultural areas, monitoring and analysis of suspended sediment and other important water quality characteristics are key elements of its water quality characterization. Water quality characterization, which involves monitoring and analysis of pertinent water quality parameters, is primarily important in the evaluation of environmental status of rivers. Information on water quality and pollution sources is paramount for the sustainable water-use management.

This study presents an analysis of suspended sediment in relatively small rivers, providing insights on the use of sediment rating curves and regression analysis using stratified data to establish better and more efficient prediction models, to estimate sediment load, and to determine the effect of agricultural activities (*i.e.* rice transplanting activities) on the rivers' annual sediment load. The study is, then, expanded to include the monitoring and analysis of other important water quality characteristics in the network of rivers. The water quality characterization studies presents the importance of water quality index (WQI) as a key element in the assessment of river water quality, and the applicability and practical use of some exploratory data analyses in the determination and interpretation of the spatio-temporal variation and primary factors of river water quality.

Suspended sediment load was observed daily for forty eight months in three relatively small agricultural rivers—Mima, Nara and Hiromi rivers—in southern Ehime Prefecture, Japan. Based on the suspended sediment transport characteristics and poor correlation of Q (discharge)-SC (sediment concentration), Q-SD (sediment discharge) relation was used to establish the suspended sediment rating curves. The rating curve, as a power equation model, was developed using linear (LLS) and non-linear least squares (NLLS) methods, applying it to the aggregated and seasonally-clustered data.

Analysis of results showed that NLLS method is more appropriate for small rivers, especially one having relatively wide range of discharge. The method produces rating curves which have higher model and estimation efficiencies, resulting to estimated loads which are

closer and not significantly different from the observed load. Likewise, data stratification during regression analysis improved the discharge-sediment load correlation and reduced regression and curve-fitting errors, thereby, improving the efficiency of the derived model equations. Clustering the months into rice and non-rice transplanting season also ameliorate the resulting regression equations, though not statistically significant. The suspended sediment load is higher during rice transplanting season, which could be partially attributed to drainage waters from rice paddy fields during land preparation and rice transplanting. The activities contribute at least 17% of the suspended sediment load during the rice transplanting season, supporting an earlier conjecture that considerable amount of sediments come from sources other than natural soil erosion.

The temporal distribution and variability of the sediment load appears to be mainly related to two major factors: rainfall and agricultural activities. The agricultural activities apparently affects the suspended sediment load during Spring, the agricultural activities and rainfall during Summer, the rainfall during Fall, and the absence of both during Winter.

The water duration analysis, with the water-hour and SL transport data composition, shows that hourly discharge data below the average or mean Q comprise a significant portion of the Q data. The water duration data and curves showed that, considering a limiting Q, the transported sediment load generally decreases as Q increases. However, considering all Q data, there is also a rise of transported sediment load at very high Q values despite a very low equivalent number of water-days which can could be attributed to the very few high Q values with equivalent extremely high SC and SD resulting to a very high SL.

For the water quality characterization, a set of quantitative data from nine water quality characteristics compute the WQI (water quality index). The evaluation was carried out using exploratory statistical analysis, *i.e.* correlation and trend analysis, ANOVA with pairwise means comparison, and multivariate statistical analyses which includes Factor Analysis to determine the more important water quality factors and Cluster Analysis to determine the variation of water quality level among sampling sites.

Results showed that the river sampling sites have ‘good’ overall water quality, and WQI and individual parameters have apparent seasonal pattern and differences. Also, the river-sampling sites with better water quality improved the water quality of the draining rivers at their confluence.

The computed WQI values indicate low water quality during spring and winter, while slightly better during summer and best during fall, as later supported by ANOVA and pairwise mean comparison analysis. This could be attributed to the fact that Spring correspond to the start of agricultural activities, especially land preparation and rice transplanting. Winter corresponds to the least-rainfall and low-discharge period and municipal effluents could have a greater effect on the water quality.

The trend analysis by box-whisker plots shows that Turbidity and TSS (total suspended solids) are extremely high during spring season decreases towards winter, indicating the apparent effect of land preparation and similar agricultural activities. FCB (fecal coliform bacteria) and $PO_4$-P (phosphate as phosphorus) are relatively high during summer and fall seasons. Conversely, DO (dissolved oxygen) deficit and $BOD_5$ (biochemical oxygen demand) are low during summer and fall seasons, as affected by higher water temperature.

Based on the Factor Analysis, the primary factors that highly influenced the water quality in the rivers are the FCB, $PO_4$-P, Turbidity and TSS. These are also the parameters that are better correlated to WQI, based on the non-parametric Spearman correlation analysis.

Cluster Analysis, coupled with pairwise mean comparison analysis, was able to determine the spatial variation of water quality and achieved a meaningful classification or grouping of the river sampling sites, based on the similarity of their water quality index.

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# CHAPTER I

# INTRODUCTION

## 1.1 Background

Suspended sediment is one of the major pollutants in streams and has been described as the most abundant. It is the most visible pollutant originating from agricultural areas, both point and non-point sources, and is the primary transport medium of fertilizers, pesticides, and other agricultural chemical particulates that contribute to the pollution of rivers (Walling and Webb, 1992; Meybeck *et al*., 1996).

Generally, suspended sediment is caused both by natural and accelerated erosion from land surfaces and stream channels. Agricultural activities cause much of the accelerated erosion due to unfavourable and poor tillage practices. Although its effects are usually seen as less dramatic, the impact of suspended sediment is great and with huge valuated economic damage (Wade and Heady, 1978). Because of these, suspended sediment is an important water quality to be monitored and estimated in rivers, and an important input in watershed water quality management. Likewise, it is an important problem to be addressed, especially in areas with high agricultural activities and erosion rates.

The temporal and spatial variability of sediment within the drainage basin is a key issue in river basin studies. Specifically, sediment transport and its downstream implications are of increasing interest for water quality and land use management. Information about sediment loads is useful for the evaluation of sediment yield erosion rates, water quality trends, ecological impacts, sediment dynamics during floods, and to assess downstream geomorphic effects (Batalla and Sala, 1994; Horowitz, 2003).

For rivers draining away agricultural areas, monitoring and analysis of suspended sediment and other important water quality characteristics are the key elements of water quality characterization. Water quality characterization, which involves monitoring and analysis of pertinent water quality parameters, is primarily important in the evaluation of environmental status of rivers (Bu *et al.*, 2010; Crosa *et al.*, 2006; Sarkar *et al.*, 2007). Moreover, information on water quality and pollution sources is paramount for the sustainable water-use management.

In rural areas, agricultural activities often influence the river water quality, whether it is pollutants from point and non-point sources. Some of the identified effects of agricultural production processes on any river body involve general water quality deterioration due to nutrient enrichment, destruction of spawning grounds for aquatic life, general fish kill and deterioration of its aesthetic value.

The evaluation of water quality has become a critical issue recently and, although water monitoring for different purposes is well-defined, the overall water quality is sometimes difficult to evaluate due to large number of samples and varying concentrations for many parameters (Chapman, 1992; Rauch *et al*., 1998).

Although any monitored parameter could be analyzed either alone or in group according to a common feature (*e.g.* nitrogen load, physico-chemical quality), such analysis provides only partial information on the overall water quality. The use of Water Quality Index (WQI) is a simple method that overcomes these problems and could provide on-hand information about the changes and trends of water quality. WQI is a value computed from a set of parameters that represents the overall water quality and pollution level (Miller *et al.*, 1986).

And to aid in further analyzing water quality, some exploratory data analysis (basically, statistical analysis) could also provide information that is simple and could readily be understandable. Statistical tools had been useful to deal with problems on data reduction, interpretation, and identification of characteristic changes in water quality parameters. One such tool is the Factor Analysis which is a multivariate statistical technique used to identify important factors that explains most of the variances of a system. It is designed to reduce the number of variables into a small number of indices while preserving the original relationship of the variables (Davis, 1986; Manly, 1986; Wackernagel, 1995). Another statistical tool found useful in environmental monitoring is the Cluster Analysis. It is a method that uses squared Euclidian distances to segregate or desegregate factors in a given system.

Factor and cluster analyses has been widely used as analysis methods in a wide variety of data as they are found unbiased in indicating associations between variables in an attempt to discriminate sources of variation and to established unsupervised pattern recognition in a data system. The usefulness of these two multivariate statistical techniques in analyzing environmental data has been reflected in the increasing numbers of papers tackling about their application (Vega *et al.*, 1998; Helena *et al.*, 1999; Singh *et al.*, 2004; Crosa *et al.*, 2006; Panda *et al.*, 2006; Ouyang *et al.*, 2006; Yillia *et al.*, 2008; Bu *et al.*, 2010). Though exploratory data analysis has already been used to evaluate other environmental data, there is still a dearth of information on the use of these analyses on water quality indices.

## 1.2 Significance and Objectives

The research study area consists of relatively small agricultural river, with watershed areas ranging from 34 $km^2$ to 190 $km^2$. It is known that seasonal suspended sediment dynamics and water quality characterization are seldom considered in relatively small rivers, much more to determine the effect of some specific agricultural activity. It is because of the assumption that water quality in these rivers, especially suspended sediment, is flood-depended and episodic, and its rarity requires little attention. On the other hand, ample literatures can be found delving on big rivers and investigation of related environmental engineering issues (UNESCO-IHP, 2002; Walling, 1983; Thomas, 1988); or on small rivers with different environment and dominant land use (Thomas, 1985; Sadeghi *et al.*, 2008).

The above premise lead to the general objective of the research, which is to analyze the suspend sediment transport and to characterize the overall water quality of agricultural rivers apparently impacted by agricultural activities along its course. The study sites are rural areas in heavily dotted with paddy rice fields, and drainage water after soil paddling and field preparation are usually drained into streams and rivers. This is especially apparent during periods of agricultural activities (spring and early summer seasons), particularly rice paddy preparation and rice transplanting. The rivers flow into the relatively clean Shimanto River (referred to as the *'last clear stream of Japan'*) in Kochi Prefecture, whose water quality has been observed to be deteriorating due to the polluted waters of its tributaries.

Specific objectives of the research are listed as follows:

a. To conduct a baseline monitoring on suspended sediment and general water quality in the study area.
b. To present a case analysis of suspended sediment transport in a small seasonally-cultivated agricultural catchment—analysing the monthly and seasonal scales and distribution, estimating the annual suspended sediment yield, and quantifying the contribution and the effect of rice transplanting activities to the rivers' suspended sediment load.
c. To determine the temporal differences in suspended sediment rating curves; and assess the difference of linear and non-linear least square methods of regression analysis.
d. To introduces the use of data stratification during regression analysis, thereby improving the sediment rating curves and enabling the use of power function model in rivers with nil and highly variable suspended sediment values.
e. To provide insights on the applications of the WQI in characterizing river water quality.
f. To conduct exploratory data analyses, *i.e.* correlation and trend analysis, ANOVA with pairwise mean comparison, and multivariate statistical analyses to assess temporal and spatial variation of water quality and the influence of different parameters on the level of water quality.

## 1.3 Scope and Outline of Thesis

The study commenced with the monitoring and analysis of the dynamics of suspended sediment in three rivers in southern Ehime Prefecture, Japan. After two years, the study expanded to include the monitoring and analysis of other important water quality characteristics in the network of four rivers, including the rivers monitored for suspended sediment; and the fourth river being the ultimate draining river and whose water quality has been apparently adversely affected by the three river tributaries.

Though the main water quality problem earlier identified was the suspended sediment, as particularly observed during spring and summer seasons, other water quality parameters were later found out to have influence on the general water quality. This results to two separate sub-studies in this thesis. The first study focuses only on the suspended sediment transport dynamics, while the second study deals on the characterization of the general water quality which involves nine water quality parameters, including the suspended sediment.

As a whole, the study site is composed of a network of four rivers: Nara, Mima, Hiromi, and Shimanto Rivers. The data on suspended sediment used in sediment transport analysis were taken from monitoring stations in only three rivers: Mima, Nara and Hiromi rivers. On the other hand, there are eight observation and monitoring stations for the water quality characterization study—one in each of the four rivers and one after its confluence with another river. Moreover, suspended sediment monitoring for sediment transport study was conducted for four years, while only a two year monitoring period for the water quality characterization. These differences between the two studies, thus, warranted the separate chapters in this thesis manuscript.

Chapter II of this thesis contains the review of related literature and related studies, providing the basic information for the terminologies and concepts used in the studies and fundamental principles of the methodologies used.

Chapter III presents the results of the suspended sediment transport study, including the study site and methodology. The results of the study includes the analysis of sediment transport characteristics and temporal variation, regression and sediment rating curves, comparison between the observed and modeled sediment loads, and quantification of the impact of rice transplanting activities.

Chapter IV discusses the results of the water quality characterization study, including the study site and methodology. It includes the analysis of water quality parameter characteristics and temporal variations, spatio-temporal variation of general water quality (WQI), and correlation between WQI and water quality parameters.

A summary of results are included after each study (Chapters III and IV). And, a general conclusion is presented in Chapter V, integrating the main output and recommendation of the two studies

# CHAPTER II

# LITERATURE and RELATED STUDIES

## 2.1 Rivers and Watersheds

Rivers are the most important freshwater resource to human. It constitutes the main water resources in inland areas for drinking, irrigation and industrial purposes; as well as uses for navigation, recreation and aesthetics. It also plays a major role in assimilating or carrying off industrial and municipal wastewater and runoff from agricultural fields, roadways and streets, which are sources of river pollution (Ward and Elliott, 1995; Vega *et al.*, 1998).

The “smallness” or “largeness” of a river basically depends on the watershed it drains. Numerous attempts have been made at trying to delimit the “small” watershed, either by actual size or by function (*e.g.* response to precipitation inputs), or types of storage (*e.g.* no ground water storage). Recognizing that there are broad groupings of factors that affect runoff and storage, *i.e.* climatic factors, hydrography, geomorphic, soils-vegetation/land use, and channel/ground water storage factors, one might best define a small watershed, as Black (1996) did, as follows: *“A small watershed is one where channel and ground water storage are not sufficient to attenuate a flood peak primarily influenced by weather and land use.”*

Small watersheds are said to have “flashy” hydrologic behavior—they exhibit higher high flows and lower low flows. Calculation of the ratio of maximum to minimum flows reveals higher values on small watersheds, an interesting but unstandardized measure of “flashiness”. In small watersheds, streamflow characteristics, nutrient chemical discharges, and suspended sediment and water yields are generally influenced by land use (Balci *et al.*, 1986).

This study uses the classification of rivers and watersheds established by the United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO) and World Health Organization (WHO) to define a “small watershed” and, thus, a “small river” (**Table 2.1**) (Meybeck *et al.*, 1996).

Table 2.1: Characteristics of a small river/watershed

| Characteristic | Limiting Value |
|---|---|
| Average discharge | < 100 $m^3/s$ |
| Drainage area | < 10,000 $km^2$ |
| River width | < 200 m |
| Stream order | < 7 |

In relation to sediment transport, small rivers and streams often depend for their suspended load on episodic contributions of fine materials from banks and upland areas. Moreover, as mentioned by Yakisch and Verhoff (1983), small rivers and streams are “event response” streams and its suspended sediment concentration depends on supply as well as discharge, thereby, sediment concentration tends to have poorer relationship with flow. On the other hand, large river systems usually contain abundant channel materials available for movement, so the energy of the water discharge is often a good predictor of the transport.

According to usage, rivers are categorized into six classes (Japan Ministry of Environment). These river classes and its uses and water quality parameter standard values are shown in **Table 2.2**.

Table 2.2: River classification, use, and standard value for physico-chemical parameters

| Class | Uses Description | pH | DO (*mg/L*) | BOD (*mg/L*) | SS (*mg/L*) | Total Coli (*MPN/100mL*) |
|---|---|---|---|---|---|---|
| AA | Water supply class 1, conserved natural environment, and uses listed in A-E | 6.5-8.5 | ≥7.5 | ≤1 | ≤25 | ≤50 |
| A | Water supply class 2, fishery class 1, bathing and uses listed in B-E | 6.5-8.5 | ≥7.5 | ≤2 | ≤25 | ≤1,000 |
| B | Water supply class 3, fishery class 2, and uses listed in C-E | 6.5-8.5 | ≥5 | ≤3 | ≤25 | ≤5,000 |
| C | Fishery class 3, industrial water class 1, and uses listed in D-E | 6.5-8.5 | ≥5 | ≤5 | ≤50 | |
| D | Industrial water class 2, agricultural water, an d uses listed in E | 6.0-8.5 | ≥2 | ≤8 | ≤100 | |
| E | Industrial water class 3 | 6.0-8.5 | ≥2 | ≤10 | | |

Water supply class 1 are waters that only needed to be purified by filters and other simple means, Water supply class 2 by sedimentation filters and other ordinary means, and Water supply class 3 by pre-treatment and advanced means. Fishery class 1 waters are for oligosaprobic members of the Salmonidae species (*e.g.* salmon and trout), Fishery class 2 for alpha-oligasoprobic products such as sweetfish, and Fishery class 3 for beta-oligasoprobic products such as carp and crucian. Industrial water class 1 are waters which need to be purified by sedimentation and other ordinary means, Industrial water class 2 with chemical additives and advanced means, and Industrial water class 3 using special means.

Linsley, *et al.* (1998) and Ward and Elliot (1998) suggested the following as the important watershed descriptors that directly and indirectly affect the magnitude of runoff and sediment yield (**Table 2.3**): (a) *Main Stream Gradient* or the ratio of the change in elevation of the mainstream from the farthest point of the watershed outlet to the main stream length; (b) *Stream Order* which is a measure of the amount of branching within a basin or to describe the drainage network in a watershed; (c) *Drainage Density* which describes the dissection of a basin that determines its response to a rainfall input; (d) *Basin Shape* or the shape of a catchment which affects the streamflow hydrograph and peak-flow rates and could also be represented by the (e) *Circulatory Ratio* or (f) *Elongation Ratio*; and (g) *Relief Ratio* or the ratio of the total basin relief (difference between highest and lowest elevation) to the maximum basin length.

Table 2.3: Formulae of the different catchment descriptors

| Descriptor | Formula | Notation |
|---|---|---|
| Main Stream Gradient | $G_{ms} = \frac{\Delta E}{L_{ms}}$ | $\Delta E$ – change in elevation from headwaters to reference point (m)<br>$L_{ms}$ – main stream length (m) |
| Stream Order | | (Strahler Method) |
| Drainage Density | $DD = \frac{SL_t}{DA}$ | $SL_t$ – total length of streams (m)<br>$DA$ – drainage area (m$^2$) |
| Basin Shape | $R_f = \frac{A}{L_b^2}$ | $A$ – basin area (m$^2$)<br>$L_b^2$ – length of basin (m) |
| Circulatory Ratio | $CR = \frac{C}{P_b}$ | $C$ – circumference of equi. circle (m)<br>$P_b$ – basin perimeter (m) |
| Elongation Ratio | $ER = \frac{D}{L_m}$ | $D$ – diameter of equi. circle (m)<br>$L_m$ – maximum basin length (m) |
| Relief Ratio | $RR = \frac{BR_t}{L_b}$ | $BR_t$ – total basin relief (m)<br>$L_b$ – basin length (m) |

## 2.2 Suspended Sediment and Agricultural Activities

The suspended sediment of a river represents the fine-grained material transported in suspension. It differs from bed load sediment in that it may be diffused throughout the vertical column of flow via turbulence. Suspended sediment particles are transported solely by convective fluxes, one associated with the mean flow motion and one associated with the turbulence of the flow (Garcia, 2008).

The suspended sediment load in this thesis refers to the sediment that is in motion in a river, consisting of the wash load and suspended-bed material load, according to the classification of sediment based on the mechanism of transport (**Table 2.4**). Suspended sediment is conventionally separated from material in solution by filtration through a 0.45-μm filter. Particles are commonly less than 0.2 mm in diameter and in most rivers the suspended load is clay- and silt-sized particles (*i.e.* < 0.062 mm in diameter).

Table 2.4: Sediment load classification

| Total sediment load | Classification System | |
|---|---|---|
| | *Based on mechanism of transport* | *Based on particle size* |
| Wash load | Suspended load | Wash load |
| Suspended-bed material load | Suspended load | Bed-material load |
| Bed load | Bed load | Bed-material load |

The presence of suspended sediment or solids in river water is an important physical characteristic. Such sediment can have both a direct effect on aquatic life through damage to organisms and their habitat and an indirect effect through its influence on turbidity and light penetration. Decreased light penetration reduces primary production and hinders the growth of benthic macrophytes. Increased sediment concentrations will also necessitate increased treatment of domestic and industrial water supplies. The effect of excessive sediment loading on receiving water includes a deterioration of aesthetic value, a loss of reservoir storage capacity, changes in aquatic population and their food supplies, and an accumulation of bottom deposits that impose an additional oxygen demand and inhibit some advantageous benthic processes.

Concern for the role of fine sediment in the transport of nutrients and contaminants through the fluvial system has generated a nod for the information on the physical and chemical properties of eroded soil and suspended sediment, as well as the consideration of load magnitude (Schwab *et al.*, 1993). Particularly, suspended sediment accounts for the majority of the transported Al, Fe, Ti, Mn, Si and P in water bodies (> 95 %); and a major proportion of the flux of several other elements like organic carbon (68 %) and organic phosphorus (94 %).

When attempting to link the suspended sediment load of a drainage basin to the erosion processes and sources operating within it, it is important to recognize that only a proportion (probably a small one) of the sediment mobilized by erosion will find its way to the basin outlet (Walling and Webb, 1992). Much will be deposited within the system.

Traditionally, investigations of the suspended sediment of streams have focused on collection of gross data concerning both concentrations and the loads. In many applications, it is the concentrations of suspended sediment occurring in a river (*i.e.* mg/L) rather than the specific sediment yield (*i.e.* t/km$^2$/year) that is of prime interest. However, the two are closely linked, since rivers with high suspended sediment yields are likely to exhibit high sediment concentrations.

Sediment production, which is the by-product of erosion, is dependent on factors such as climate, soil type, land use, and topography. Among these, however, land use is the variable and is the most significant. Taking into account geology, soils, topography and climate as uncontrollable factors, sediment discharge in runoff and effluent-receiving streams heavily depends on vegetative and land-use practices, especially in agricultural areas. Thus, essentially, the sources of sediment are limited to watershed erosion (natural soil erosion) and agricultural activities (*e.g.* paddy rice fields).

Modern agriculture and its components (land tillage, irrigation, and nutrient and pesticide application) had long been recognized as a significant non-point source of water pollution. Most especially, control of pollution from agricultural runoff has received emphasis due to sedimentation and water quality deterioration, as chemical fertilizers and pesticides which are used in great quantities to maintain high levels of crop production may be carried off the land by sediment or in surface runoff, adding to the pollution of downstream waters.

Thus, recent assessments of both the on-farm and off-farm costs of sediment have emphasized the relevance of research in the field of erosion and sedimentation. This has been further underscored by an increasing awareness of the importance of sediment-associated transport in the movement of contaminants through the aquatic ecosystems.

## 2.3 Sediment Transport, Load Estimation, and Analysis

### 2.3.1 Sediment Production and Transport

Suspended sediment yield is the total suspended sediment flow from a watershed or drainage area past a point of reference or gauging station, usually expressed in weight per unit time, and delivered to the downstream channels or stream network as a result of subsequent transport of detached particles.

The transport of sediment in rivers and the study of sediment yield, together with erosion, had long established itself as an important area of water resources research. It is important with respect to pollution, channel navigability, reservoir filling, hydroelectric-equipment longevity, fish habitat, river aesthetics, and scientific interests (Williams, 1989). Particularly, the detachment and subsequent transport of soil particles may give rise to the problems of channel and reservoir sedimentation, not to mention the degradation of water quality of the draining rivers and water bodies (Walling and Webb, 1981).

River systems are dynamic in nature and summary statistics such as annual suspended sediment yields and average concentrations can fail to convey a sense of the extreme temporal variability of suspended sediment transport in most rivers. For much of the time, rivers may transport very little suspended sediment and the water will be essentially clear. A large proportion of the suspended sediment transport occurs during storm events when rainfall and storm runoff mobilize sediment from the upstream watershed and channel network.

Maximum suspended sediment concentrations and loads are commonly transported during flood events and geomorphologists have frequently attempted to assess the relative importance of high-magnitude, low frequency flood events and smaller more frequent events to the long-term sediment load. Lack of long-term records and the difficulties of measuring sediment transport during rare high-magnitude events severely hampers such analysis.

Numerous studies conducted have estimated the suspended sediment during single hydrologic event or individual floods, instead of aggregate data during the whole monitoring period—consisting of both normal and high flow (Olive and Rieger, 1985; Walling and Webb, 1987; Sadeghi *et al.*, 2008). These studies have shown that the bulk of the sediment in most streams is transported during few floods and that the Q-SC relation is highly variable. However, this approach seems inappropriate when considering annual sediment yield as affected by seasonal sediment variation and anthropogenic factors.

### 2.3.2 Suspended Sediment Load Estimation and Analysis

There are several approaches in the estimation of river suspended sediment. This can be summarized into three main categories: *basin scale erosion model approach* (Mendicino, 1999; Iadanza and Napolitano, 2006), *theoretical approach* (Maidment, 1992), and *empirical approach* (Jansson, 1992; Cordova and Gonzalez, 1997; Lenzi and Marchi, 2000; Achite and Ouillon, 2007; Sadeghi et al., 2008). The *basin scale erosion models* proved to be tedious and the uncertainty in determining the sediment delivery ratio makes it less likely to be used in sediment yield. More so, *theoretical models* requires adequate knowledge of hydraulics and hydrodynamic and requires extensive validation (Shanahan *et al.*, 1998). This leaves the *empirical approach* as the most readily available method and, in fact, more accurate in estimating sediment yield.

With the *empirical approach*, researchers typically estimate total sediment loads from a series of statistical techniques (*e.g.* rating curves, interpolation) developed based on discrete sampling. Using empirical relation, suspended sediment load is represented by sediment rating curves derived from discharge-sediment load correlation. Generally, a direct positive relationship exists between river discharge (Q) and sediment load (S) and is, basically and most often, defined by a power function expressed as $S=aQ^b$, where $a$ and $b$ are constants. The methods to develop power equations vary as much as there are different models or techniques that may be adapted.

Most quantitative studies of suspended sediment load using empirical approach used suspended sediment rating curve derived from discharge-suspended sediment concentration (Q-SC) relationship by least-square methods after logarithmic transformation of the data or by directly derivation using non-linear regression in the form, $SC=aQ^b$ (Fergusson, 1986, Hasnain, 1996, Jansson, 1996, Crawford, 1991). However, this is sometimes not applicable due to high scatter of data and the consequent poor correlation between Q and SC, nor to rivers with wide range of SC (Horowitz, 2003). This limitation, however, may be ameliorated by the use of discharge-suspended sediment discharge (Q-SD) relationship (Restrepo and Kjerfve, 2000).

The applicability of the regression methods to derive the sediment rating curve, *i.e.* power function by non-linear least square method (NLLS) and detransformed logarithmic function by linear least square (LLS), may well depend on the size of the river. Previous studies on suspended load estimation generally dealt with big rivers. The uncertainty of using such methods in small rivers is due to the fact that sediment transport in big rivers is different from that in small rivers. Big rivers usually contain abundant suspended materials for movement, so the energy of the water discharge is often a good predictor of sediment transport, while small rivers depend for the suspended load on infrequent and episodic contributions from upland areas during flood and high rainfall events (Thomas, 1985).

Some literatures mentioned that sediment transport in small rivers displays greater variability among events than that of larger river (Lenzi and Marchi, 2000). The proportion of suspended sediment to total sediment load is also highly variable, usually ranging from 20% to 90% (Diez *et al.*, 1988; Billi *et al.*, 1994) when compared to that of low-land rivers which varies from 70% to 95% (Simons and Senturk, 1977; Walling and Webb, 1983). Further, in small rivers big difference in mean daily flows and extreme instantaneous flows during the day introduces large errors in sediment yield estimation (Cordova and Gonzalez, 1997). However, mitigating procedure may be use, *i.e.* using mean values within discharge classes (Jannson, 1996; Walling and Webb, 1981).

Generally, as mentioned earlier, a direct positive relationship exists between river discharge and suspended sediment—in terms of concentration or discharge. However, unique relationship between discharge and suspended sediment concentration does not appear to persist over space or time. Suspended sediment rating curves based on sediment concentration commonly have a high scatter, and the error term in fitted regressions is expectedly large (Grimshaw and Lewin, 1980). Moreover, based on studies conducted by Jansson (1985a, 1985b, 1992, 1996), it is not easy to establish a single relationship between sediment concentration and water discharge because of the differences in the level of concentration for different high water events and because of the different hysteresis (lagging of sediment concentration behind discharge rise) relationship for each event.

Further, discharge-sediment relationships have been shown to vary with season, and with the size of the material transported (Grimshaw and Lewin, 1980). Situations have been observed which involved lead or lag effects or sediment concentration with respect to discharge, hysteretic loops when there are phase differences between water discharges and sediments, “flushing” effects at the onset of storm runoff periods, and “exhaustion” effects when one discharge event follows upon another. Thus, in many cases, river discharge-sediment discharge is more appropriate in establishing sediment rating curve.

According to Jansson (1996), the problem of making a reliable sediment curve is primarily a problem of sampling strategy. With equal-time sampling, the frequency distribution of sediment concentrations for a certain water discharge will correspond to the probability distribution of the population of sediment concentrations at the discharge. More so, the aim of establishing a sediment rating curve must be a long-term average relationship between water discharge and sediment load.

#### 2.3.2.1 Non-linear least square method (Power Function Regression)

A power function regression is used to be directly developed by non-linear least squares (**NLLS**). However, a power function developed iteratively using a least-square method has been found to give regression equations that calculate the load reasonably accurately if it converges to a solution (Jansson, 1985a,b 1992; Crawford, 1991). Both cases assumes a model function, as,

$$SD = aQ^b \tag{2.1}$$

Crawford (1991) compared power equation rating curves developed as power function regressions and as logarithmic regression corrected for bias, and found out that power function regressions gave a smaller sum of squared errors compared with regressions constructed as retransformed logarithmic regressions, corrected for bias.

However, the results of Crawford (1991) as cited by Jansson (1996) mean that even if the error sum of squares is small the reproduceability of an iteratively developed power function regression is low. Crawford (1991) argued that the predictive capability of the model is low, as the prediction-error sum of squares is high. The prediction–error sum of squares was high for the power function regressions because high values affect a power function regression very much, and is low for the corrected retransformed logarithmic regressions. He concludes that even though the sum of squared errors is smaller with the power function regression model it should not be used because the predictive capability is low due to the strong influence of a few high discharges.

#### 2.3.2.2 Linear least square method (Detransformed Logarithmic Function Regression)

Suspended sediment concentration or load has a log-normal distribution. A variable is said to have a log-normal distribution if the logarithm of a variable is normally distributed. Therefore, it has been common practice to log-transform the data to obtain a normal distribution and to develop a linear regression equation on the logarithms with least-square methods (**LLS**), as follows,

$$LogSD = Loga + bLogQ \qquad (2.2)$$

which can be retransformed (back-transformed) to

$$SD = 10^{\log a} Q^{b} \qquad (2.3)$$

This retransformed logarithmic regression is different from a power function regression as regards to the residual terms. The residual term is additive in the power function regression model but multiplicative in the log-transformed model (Jansson, 1985a,b).

Power Function Regression:

$$SD_1 = \alpha_1 Q^{\beta_1} + \varepsilon \quad \{\text{where is } \boldsymbol{\varepsilon} = \text{N}(0, \sigma^2)\} \qquad (2.4)$$

Detransformed Logarithmic Regression:

$$SD_2 = \alpha_2 Q^{\beta_2} \bullet \xi \qquad (2.5)$$

which can be log-transformed to

$$LogSD_2 = Log\alpha_2 + \beta_2 LogQ + Log\xi \quad \{\text{where } \log\zeta \text{ is assumed N}(0, \sigma^2)\} \qquad (2.6)$$

That the models are different can also be understood from the fact that a power function regression curve must go through the arithmetic means whereas a detransformed logarithmic regression curve must go through the geometric means, that is to say, means of logarithms (Jansson, 1996). The geometric means are systematically lower than the arithmetic means.

#### 2.3.2.3 Data stratification and mean loads

Power function regression gives great weight to high values at high discharges whereas logarithmic regression gives weight to low values at low water discharges. This great weight can control the direction of the regression curve too much in both cases. The solution for this problem is the stratification of discharge into classes together with the corresponding sediment load.

With the calculation of mean loads in water discharges, the frequency of data in certain discharge intervals does not affect the regression. By using the mean loads and mean water discharges, the problem that often occurs with the logarithmic model, *i.e.* that a high frequency of low loads determines the appearance of the rating curve, could be avoided. Waling and Webb (1981) showed that when using mean loads in water discharge classes, the order of magnitude of the load is correct. The use of mean loads within water discharge classes for the development of sediment rating curves has also been suggested by Jansson (1985a,b).

## 2.4 Water Quality and Agricultural Activities

Water quality refers to the physical characteristics, dissolved chemical constituents, and bacteriological quality of water, with reference to a specific use. Water quality constituents can include sediment, nutrients, pesticides, heavy metals, oxygen-demanding wastes, and disease-causing organisms (Ffolliott, 1990). If it has a good water quality, rivers and other freshwater ecosystems play a unique role for society through providing products and food, supporting water processing and supply of clean water, and enriching or cultural service such as aesthetic and recreational activities. However, with the development of industry and agriculture, the number and magnitude of anthropogenic stressors arose from the myriad of human activities including pollution and overexploitation of water resources.

Worldwide deterioration of surface water quality has been attributed to both natural processes and anthropogenic activities, including hydrological features, climate change, precipitation, agricultural land use, and sewage discharge (Bu *et al.*, 2010; Crosa *et al.*, 2006; Zhou *et al.*, 2007). Most especially, rivers and streams are usually polluted due to anthropogenic activities, such as industrial, sewage, and agricultural discharges.

Other than its significant contribution to sediment load in surface waters, agricultural practices have an expected negative impact on the general water quality. Improper agricultural methods may elevate concentrations of nutrients, fecal coliforms, and sediment loads. Increased nutrient loading from animal waste can lead to eutrophication of water bodies which may eventually damage aquatic ecosystems. Animal waste may also introduce toxic fecal coliforms which threaten public health. Grazing and other agriculture practices may intensify erosion processes raising sediment input to nearby water sources. Increased sediment loads make drinking water treatment more difficult while also affecting fish and macroinvertebrates.

## 2.5 Water Quality Monitoring, Index and Parameters

The burgeoning problems and issues of water quality warrants the need of a periodic water quality monitoring, As defined by International Standards Organization (ISO), water quality monitoring is a programmed process of sampling, measurement, and subsequent analysis of various water characteristics, often with the aim of assessing conformity to specified objectives. The most common water quality parameters measured in rivers are those related to water pollution and its information is essential not only to highlight the actual quality of the rivers but to enable the relevant authorities to take necessary course of actions.

Particularly, river quality monitoring is an important component of water quality management. Water quality data produced by a river water quality monitoring program is widely used to determine the background quality of a water body and its possible uses, to identify changes or trends over time, and to identify and prioritize for abatement, prevention and control of sources and pathways of pollution.

Water monitoring and evaluation for different purposes has already been established and well-defined. However, the overall water quality is sometimes difficult to evaluate due to large number of samples and varying concentrations for many parameters (Chapman, 1992; Rauch *et al*., 1998). Although any monitored parameter could be analyzed either alone or in group according to a common feature (*e.g.* nitrogen load, physico-chemical quality), such analysis provides only partial information on the overall water quality. The use of Water Quality Index (WQI) is a simple method that overcomes these problems and could provide on-hand information about the changes and trends of water quality.

WQI is a value computed from a set of parameters that represents the overall water quality and pollution level. Unlike mathematical and computational modeling that requires adequate knowledge of hydraulics and hydrodynamics and requires extensive validation (Chapman, 1992; Shanahan *et al.*, 1998; Somlyody *et al.*, 1998), WQI is a simple and understandable tool that attempts to provide a mechanism for presenting a cumulatively derived numerical expression, defining water quality (Miller *et al*., 1986). The WQI can give an indication of the health of the watershed at various points and can be used to keep track of and analyze changes over time. The WQI can be used to monitor water quality changes in a particular water supply over time, or it can be used to compare a water supply's quantity with other water supplies in the region or from around the world

The first WQI was developed in 1970's and has been applied in water quality studies in many parts of the world, including Africa and Asia (Suki *et al*., 1989; Zou *et al.*, 1988; Erondu and Ndukda, 1993; Sarkar *et al.*, 2007). To date, a broad range of different water quality indices categorizing water bodies have flourished in literatures. They can be classified according to the type of variable they consider, as: physico-chemical, biological, and hydromorphological WQIs (Terrado, 2010). In the same way, the WQI approach in water quality evaluation has many variations in the literature and comparative evaluations have recently been undertaken in many studies and published papers (Ott, 1978; Pesce and Wunderlin, 2000; Karami *et al.*, 2009).

The present study is initially based on the National Sanitation Foundation WQI, which is an index for general water quality evaluation developed by a US-based environment organization and an arm of USEPA and WHO. The index is a combination of physico-chemical, inorganic and bacteriological indicators, as follows,

- **Temperature**

  The water temperature of a river is very important, as many of the physical, biological, and chemical characteristics of a river are directly affected by temperature. It governs the kinds and types of aquatic life, regulates the maximum DO concentration in water, and influences the rates of chemical and biological reactions(Ffolliott, 1990). Specifically, the higher the water temperature the higher the rate of chemical metabolic reactions, as the solubility of oxygen in water is inversely related to the water temperature.

- **pH**

The pH level is a measure of the acid content of the water. The value of pH is a significant factor for water ecosystems, including toxicity to vegetation and animals (Bu, *et al.*, 2010). Most forms of aquatic life tend to be sensitive to pH and water containing high organic pollutants will normally tend to be somewhat acidic. Water with a pH of 7 is considered neutral. If the pH is below 7, it is classified as acidic, while water with a pH greater than 7 is said to be alkaline. At extremely high or low pH levels (9.6<pH<4.5), the water becomes unsuitable for most organisms.

- **Turbidity**

Turbidity is a measure of the dispersion of light in a column of water due to suspended matter. The higher the turbidity, the cloudier the water appears. If water is turbid, it loses the ability to support a wide variety of plants and aquatic organisms. When the water is turbid, heat from the sun is absorbed and cause the temperature to rise. Higher temperature cause oxygen level to fall and deters photosynthesis, limiting the ability of aquatic organisms to survive.

- **Total Suspended Solids (TSS)**

Suspended solids and sediments largely determines the physical quality of water in the streamflow. It is important because it can restrict sunlight from photosynthetic plants, and can adversely affect aquatic ecosystems by smothering benthic communities and gravels that often are important spawning habitats for fish. It also carries nutrients and heavy metals that can impact the quality of the water (Ffolliott, 1990; Bu *et al.*, 2010).

High concentration of suspended solids may also lead to an increase in water temperature. Sources of harmful suspended solids are many, such as: runoff from urban areas, fertilizer and pesticides, wastewater from sewage treatment plants, decayed plants and animal matter, disturbed the soil, and soil erosion.

- **Dissolved Oxygen (DO)**

DO is a measure of the amount of life-sustaining oxygen dissolved in the water. This is the oxygen available to fish, invertebrates, and all other animals living in the water. Low level of DO in water is a sign of possible pollution, as DO levels fall in the presence of organic waste (Ffolliott, 1990). Organic wastes come from untreated or poorly-treated sewage, runoff from farm and animal feedlots, and natural sources like decaying aquatic plants and animals.

The DO content is determined, in large part, by the water temperature and biological activity. It, therefore, is a highly transient property that can fluctuate in time and space. From a biological standpoint, DO is one of the more important water quality characteristics.

- **Biochemical Oxygen Demand (BOD)**

  BOD is a measure of the amount of food for bacteria that is found in water. Bacteria utilize organic matter in their respiration and remove oxygen from the water. The BOD test provides a rough idea of how much biodegradable waste (usually composed of organic wastes) is present in the water.

  BOD directly affects the amount of dissolved oxygen in rivers and streams. The more rapidly oxygen is depleted in the stream, the greater the BOD. A high BOD harms stream health in the same way as low DO, posing risk and death of aquatic organisms.

- **Nitrates ($NO_3$-N)**

  Nitrates are a measure of the oxidized form of nitrogen and are essential macronutrients in aquatic environment. Nitrate-nitrogen is commonly an indicator of nitrogen-containing fertilizer or pesticidal contamination. High concentration of nitrate-nitrogen can stimulate the growth of aquatic plants and affects fish species. Likewise, nitrates can be harmful to humans because our intestines can break nitrates down to nitrites which affect the ability of red blood cells to carry oxygen.

  Sources of nitrogen include the fixation of nitrogen by bacteria and plants, the addition of organic materials to water bodies, and the amounts from weathering rocks. Organic nitrogen breaks down into ammonia, which then becomes oxidized to nitrate-nitrogen, a form of nitrogen that is available to plants. Streamflows from undisturbed watersheds usually contain lower concentrations of total nitrogen and nitrate-nitrogen than streamflows from watersheds subjected to agricultural use or urbanization (Ffolliott, 1990)

- **Phosphates ($PO_4$-P)**

  Phosphorus is usually present in natural waters, and almost solely, as $PO_4^{-3}$. They are necessary for plants and animal growth and is an indicator of phosphate-containing fertilizer contamination.

  Phosphorus/phosphates originate from weathering of igneous rocks, soil leaching and organic materials. Its concentration in streams is greatly affected by land use practices in a manner that is similar to those of nitrogen. Problems of eutrophication are often associated with accelerated loading of phosphorus in waters that are naturally deficient in phosphorus.

- **Fecal Coliform Bacteria (FCB)**
  Fecal coliform bacteria are indicators of contaminants caused by animal and human wastes. They are indicator organism which means that it does not cause disease in human but it may indicate the presence of other pathogenic bacteria. If FCB counts are high (over 200 colonies/100mL of water sample), it is very likely that pathogenic organisms are also present. Disease and illness such as typhoid fever, hepatitis, gastro-enteritis, and dysentery may result from contact with water having FCB. Hence, as a bacteriological indicator, FCB is often used to determine if the water can be used for drinking, swimming, and other forms of human contact.

## 2.6 Exploratory Data Analysis

Statistical analysis of water quality provides information that is simple and could readily be understandable. In fact, statistical methods is important in water resource management and its application covers a range of topic, from formulating environmental standards to designing monitoring programs and interpreting results.

Statistical analysis, to the very least, is used in water sampling activities, hypothesis testing, uncertainty intervals, and comparison tests. Other basic uses of statistical methods are determination of average and measures of dispersion of water quality variables, identifying long-term trends with stated probability, verifying whether a standard has been met with specified level of confidence, and estimation or prediction of parameters (McBride, 2005).

Analysis of Variances (ANOVA), correlation and trend analysis, regression analysis, and test of significant difference are just some of the basic statistical methods which can be explored and adapted to analyze water quality.

Moreover, some statistical tools had been useful to deal with problems on data reduction, interpretation, and identification of characteristic changes in water quality parameters. One such tool is the Factor Analysis which is a multivariate statistical technique used to identify important factors that explains most of the variances of a system. It is designed to reduce the number of variables into a small number of indices while preserving the original relationship of the variables (Davis, 1986; Manly, 1986; Wackernagel, 1995). Another statistical tool found useful in environmental monitoring is the Cluster Analysis. It is a method that uses squared Euclidian distances to segregate or desegregate factors in a given system.

Factor and cluster analyses has been widely used as analysis methods in a wide variety of data as they are found unbiased in indicating associations between variables in an attempt to discriminate sources of variation and to established unsupervised pattern recognition in a data system. The usefulness of these two multivariate statistical techniques in analyzing environmental data has been reflected in the increasing numbers of papers tackling about their application (Vega *et al.*, 1998; Helena *et al.*, 1999; Singh *et al.*, 2004; Crosa *et al.*, 2006; Panda *et al.*, 2006; Ouyang *et al.*, 2006; Yillia *et al.*, 2008; Bu *et al.*, 2010).

In fact, many exploratory data analysis has already been used to evaluate environmental data, but there is still meager information on the use these analyses in combination with water quality indices.

# CHAPTER III

## SUSPENDED SEDIMENT TRANSPORT ANALYSIS

### 3.1 Study Site

The research area consists of three river tributaries of Shimanto river located within the Ehime Prefecture: Mima, Nara and Hiromi rivers. Shimanto River is a big river located in Kochi Prefecture (**Fig. 3.1**). It is sometimes referred to as the "*last clear stream of Japan*" and one of the very few big rivers in Japan with no dams along its course because of its subtle slope. It is also named as one of the "*Three Clear-flowing Rivers in Japan*", along with Nagara River in Gifu Prefecture and Kakita River in Shizuoka Prefecture.

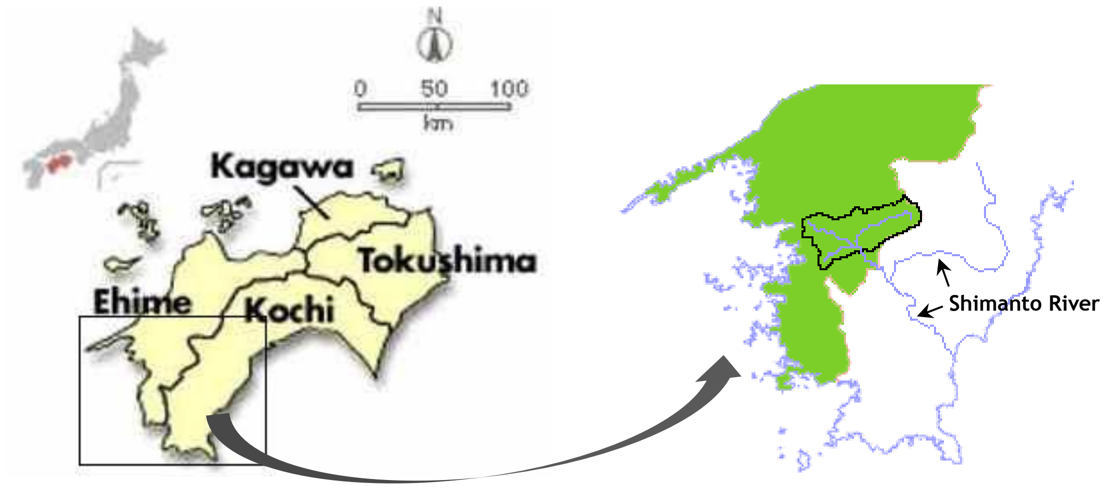



Figure 3.1: Study site relative location in Japan, Shikoku Island and Ehime Prefecture.

The Mima river watershed is composed of the former town of Mima (now merged with the Uwajima City) and a portion of the town of Kihoku. Nara river watershed is found in the southeastern part of the town of Kihoku. Hiromi river watershed, on the other hand, includes most part of the town of Kihoku which is a merger of the former town of Hiromi and village of Hiyoshi. In fact, Nara river flows into Mima river, Mima river flows into Hiromi river and Hiromi river flows into Shimanto river (**Fig. 3.2**). Thus, Hiromi river is a tributary of Shimanto river while Nara and Mima rivers are sub-tributaries.

Hiromi river is one of the biggest tributaries of the Shimanto river, located in its middle course and is observed to discharge sediment-laden and ‘polluted’ waters, especially during the months of April to September which corresponds to the agricultural production season (particularly rice planting) in the areas. Its waters flow into the Shimanto river that apparently deteriorates the latter’s water quality.

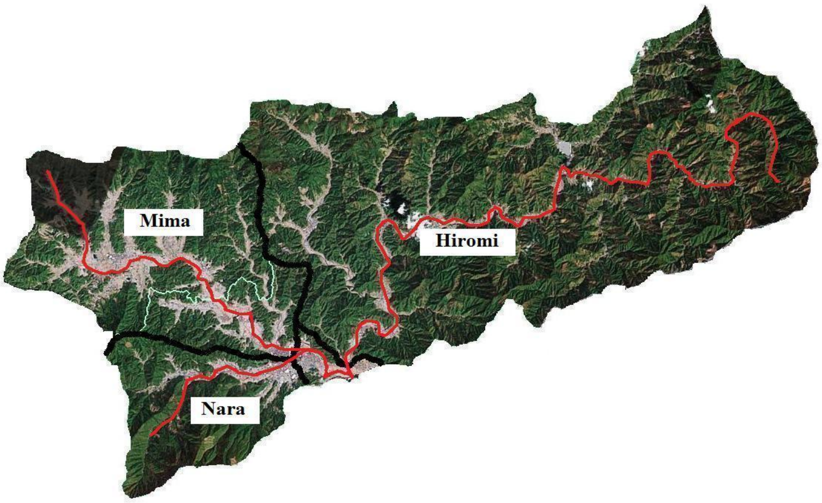



Figure 3.2: The study area showing elevation profile, watershed divide and main stream of Mima, Nara and Hiromi river watersheds

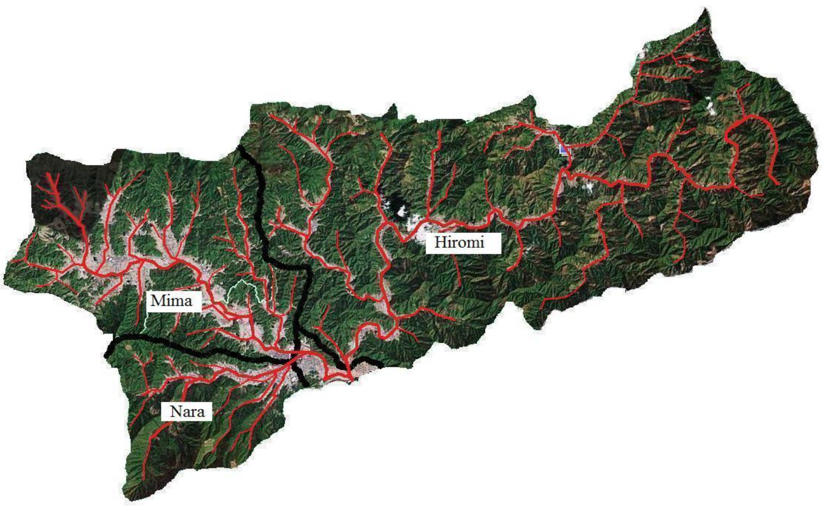



Figure 3.3: The study area showing the river network (essential in determining the stream order and drainage density)

### 3.1.1 Watershed Characteristics and Land Uses

The defining characteristics and land uses of the watersheds draining water from the three rivers is shown in **Table 3.1**. Hiromi is the biggest watershed with an area more than twice and seven times the size of Mima and Nara watersheds, respectively. Also, its main stream is more or less twice and five times longer than that of Mima and Nara, respectively. Although having the smallest watershed area and shortest main stream, Nara river has the highest main stream gradient or river slope per unit distance, approximately three times and six time than that of Hiromi and Mima rivers, respectively. This implies that given a certain erosive rainfall event, Nara river has the shortest time of concentration and will reach peak flow and peak sediment load the earliest. This is also supported by the fact that it has a low stream order, highest drainage density, highest relief ratio, and more circular shape—watershed characteristics that, theoretically, result to a shorter time of concentration and faster peak flow.

Table 3.1: Watershed characteristics and land use

| Descriptors | River Watersheds | | |
|---|---|---|---|
| | **Nara** | **Mima** | **Hiromi** |
| Area, $km^2$ | 34 | 73 | 190 |
| Main stream length, km | 8 | 17 | 37 |
| Main stream gradient, m/m | 0.062 | 0.010 | 0.021 |
| Stream order | 3 | 3 | 4 |
| Drainage density, $m/m^2$ | 0.999 | 0.957 | 0.577 |
| Basin shape | 0.438 | 0.334 | 0.436 |
| Circulatory ratio | 0.726 | 0.625 | 0.638 |
| Elongation ratio | 0.652 | 0.747 | 0.745 |
| Relief ratio | 0.054 | 0.013 | 0.038 |
| Land Use, $km^2$ (%) | | | |
| Forest | 50 (*69%*) | 28 (*82%*) | 166 (*87%*) |
| Arable land | 8 (*11%*) | 1.5 (*4%*) | 5 (*2.5%*) |
| Others (*residential, etc.*) | 15 (*20%*) | 4.5 (*14%*) | 20 (*10.5%*) |
| Rice paddy (*as % of total area*) | 7 (*9%*) | 1 (*3%*) | 3.5 (*2%*) |
| Rice paddy (*as % of arable area*) | 7 (*88%*) | 1 (*80%*) | 3.5 (*70%*) |
| Rice transplanting season | April-May | April-June | April-May |

The watersheds are basically forested (69-87%) with only a small fraction as arable area (3-11%), and the other area being residential, grazing or fallow lands (11-20%). This is typical of any land in Japan where forest covers at least 65% of the total area. The arable land is generally apportioned to rice and vegetable production, with rice paddy field comprising at least 70%—making it a significant land use (**Table 3.1**). Rice production is the biggest agricultural activity, with land preparation activities starting as early as the end of March. Among the activities, the soil paddling produces considerable amount of sediment as paddy fields are flooded and highly-sedimented waters are at least partially-drained just before or during rice seedling transplanting, flowing towards streams and rivers.

In Mima and Nara river watersheds, the rice paddy areas lie almost entirely along the course of the rivers and their sub-tributaries. The paddy rice fields in the towns of Kihoku and Matsuno are located almost entirely along the course of Hiromi river, together with the paddy rice fields that lie along the Mima and Nara Rivers within the boundary of the town of Kihoku.

The paddy rice land area and planting season/schedule in **Table 3.3** and **Fig. 3.4** shows that rice transplanting in Mima watershed spans three months (April-June). Transplanting in Nara is less than 2 weeks and is scheduled in the last dekad of April; while transplanting in Hiromi lasts for 2 weeks and is scheduled in the first half of May.

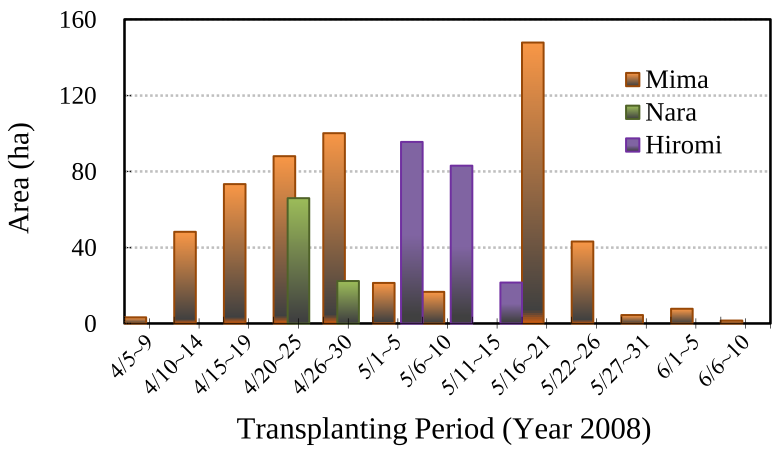



Figure 3.4: Paddy land area and transplanting schedule in Mima, Nara and Hiromi

The last dekad of April and the first half of May is the busiest period in the schedule of rice transplanting in the watersheds. During this period, all three areas have rice transplanting activity in a significant portion of its area, with 100% already planted in Nara and Hiromi and around 40% planted in Mima.

### 3.1.2 Rivers and Sampling Sites

Nara river is approximately 8 km long and is entirely located in the town of Kihoku. The observation and sampling site for Nara river (water sampler and water level meter) is located 1.6 km before its confluence with Mima river (*refer to* **Fig. 3.5**).

Mima river is approximately 17 km long and is joined by the Nara river approximately 2.5 km before its confluence with the Hiromi river, in the town of Kihoku. Its headwaters are located in the town of Mima but a significant portion of its downstream is located in the town of Kihoku. The observation and sampling site for Mima river where the automatic water monitoring equipment (automated water sampler, turbidity meter and water level meter) is located almost 1 kilometer before its confluence with Nara.

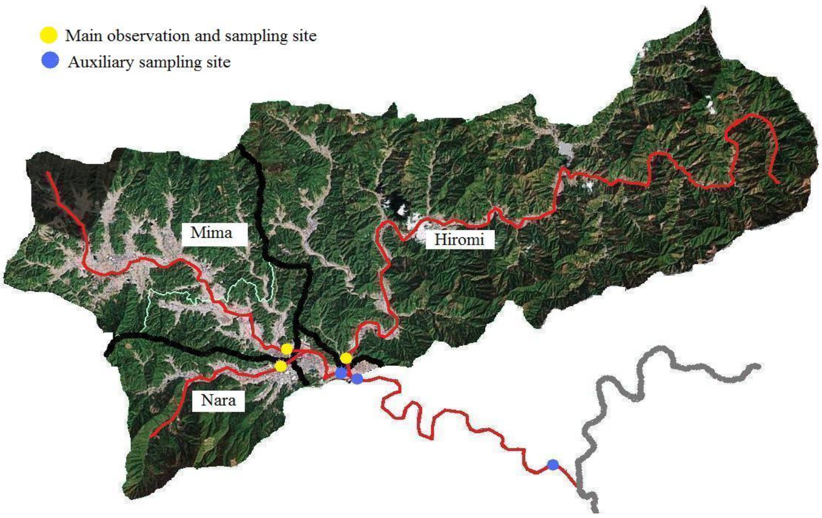



Figure 3.5: The watersheds showing the main stream, observation station and sampling sites and auxiliary sampling sites

Hiromi river has a total main stream length of approximately 56 km long and its headwaters located in the town of Kihoku. Its course passes through the towns of Kihoku and Matsuno in Ehime Prefecture and flows out to Shimanto river in Shimanto City, Kochi Prefecture, approximately 21 km after its confluence with Mima river.

The sampling site (water sampler) for Hiromi river is located just before its confluence with Mima river, forming a main stream length of 37 km from its headwaters (*refer to* **Table 3.1**). However, the observation station where the water gage is installed and river flow measurement is done is around 2.5 km upstream, as there is no appropriate location (*i.e.* gauging station or weir) for river discharge measurement on or near the water sampling site. As there is only one small tributary and few hectares of rice fields located between the between the observation and sampling sites, it is presumed that there is no significant difference on the discharge and sediment load between the two locations.

Three other auxiliary sampling sites were established during the later part of the study period: (1) Lower Mima sampling site which is located downstream and just approximately 100 meters before the Mima and Hiromi Rivers' confluence, (2) Mima-Hiromi confluence sampling site which is located just around 200 meters below the rivers' confluence and (3)

Lower Hiromi sampling site which is located 20 km from Mima-Hiromi confluence and 1 km before Hiromi-Shimanto River confluence (**Fig. 3.5**).

The data of the three auxiliary sampling sites were used to verify the amount of sediment load before and after the confluences and to attest the relationship of sediment loads transported between the upstream and downstream sampling sites. An automatic water sampling equipment was installed in the Lower Hiromi sampling site while manual sampling is done in the Lower Mima and Mima-Hiromi confluence sampling site using composite sampling- in the left, center, and right portion of the river width. These sampling sites were also used in the overall water quality monitoring activities (*refer to* **Fig. 4.1**).

## 3.2 Data Gathering, Sampling and Laboratory Analysis

The rivers were monitored for four years, *i.e.* from April 2008 to March 2012. Data gathered includes precipitation, river discharge and suspended sediment concentration.

The precipitation data was taken from the AMeDAS station located at Chikanaga District in the town of Kihoku near the Nara and Mima river sampling sites and few kilometers away from the Hiromi river sampling site. The daily and hourly data were downloaded and used in the data analysis.

The area has an average annual rainfall of 1,995 mm. The wettest period is June-October, with a mean monthly rainfall of at least 250 mm. The wettest month is June and the driest December. Rainfall season starts on June and most typhoons are recorded during summer (June-August) and early autumn (September-October). Rice production season corresponds to the spring and summer seasons which are also the period of typhoons and high rainfall.

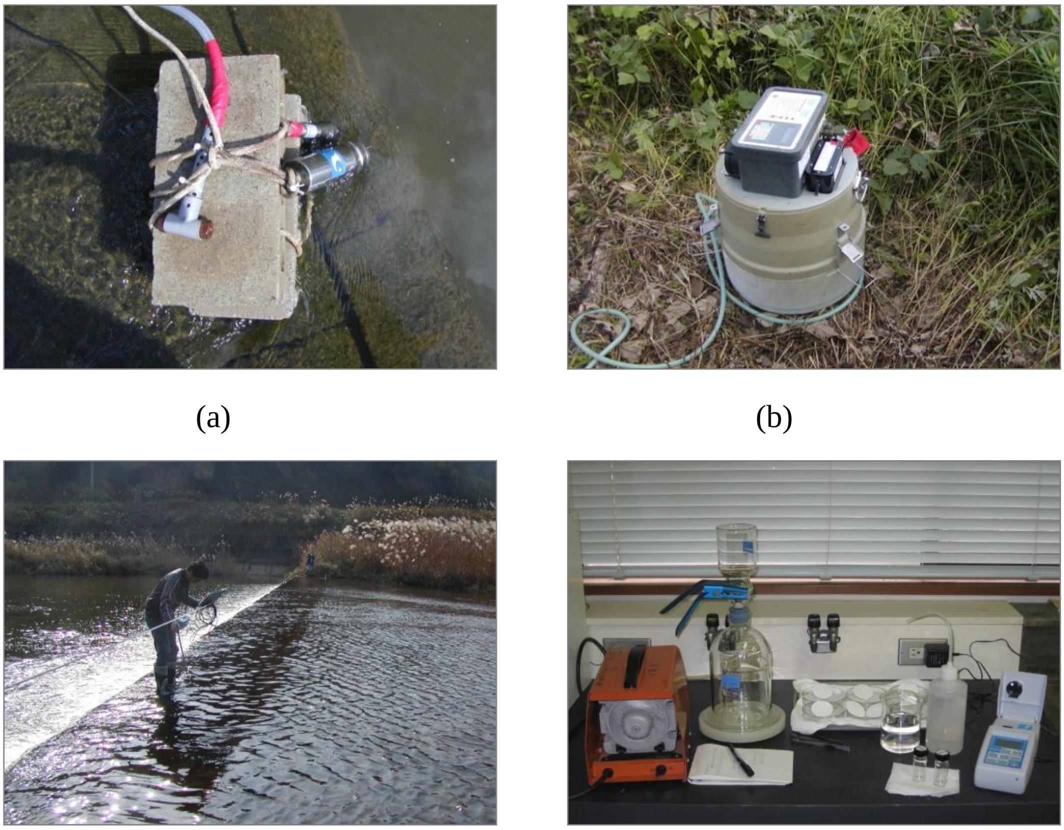
River discharge is monitored by measuring the river's stage using a data-logging water gage (**Fig. 3.6a**). River stage data is measured every hour and translated into actual water depth by regularly measuring the depth of water gage. The actual flow of the river was measured regularly using a digital flow meter and applying the sectional velocity method to compute the discharge (**Fig. 3.6c**). The procedure is done once or twice a month at the nearby weir in the observation station. A rating curve (water depth versus discharge) was established from numerous actual measurements, in the form,

$$\boldsymbol{Q = aH^b} \tag{3.1}$$

where $\boldsymbol{Q}$ is discharge ($m^3/s$), $\boldsymbol{H}$ is water depth (m), and $\boldsymbol{a}$, $\boldsymbol{b}$ are regression constants. The curve (equation) is used to determine the hourly discharge using the monitored hourly stage or water depth monitored.

Water samples to determine the sediment concentration were collected by an automated water sampling machine (**Figs. 3.6a** and **3.6b**). Automated sample collection is essential and more effective as frequent manual sampling would be quite difficult, if not impossible. The suction hose of the machine used is set up together with the water gage, tied in a hollow block and plunged in an appropriately chosen location in the weir (**Fig. 3.6a**). It collects 500 mL of water sample per sampling.

The water sampling is done in a 24-hour time interval (once daily), thus, generating a time-series sediment concentration data. However, in order to closely monitor the more erratic fluctuation of sediment concentration during the rice production season, sampling was done in a 12-hour interval (twice daily) during the spring and summer seasons, particularly during the months of April to September. The 12-hour interval was found sufficient to represent the hourly fluctuations in a day, based on the 24-hour hourly monitoring conducted three times (*refer to* **Appendix Fig. 5**). Thus, sampling is done once a day during October-March and twice a day during April-September.



(a) (b)

(c) (d)

Figure 3.6: (a) Gage set-up showing the water gage, turbidity meter and suction hose of automated water sampler, (b) Automated water sampling machine, (c) River discharge measurement and (d) Laboratory analysis set-up

The sediment concentration was determined using the filtration-oven method (Ffliott, 1990): filtering a 200 ml water sample using a 0.45-µm filter paper, drying the filtered sample at an approximately 100°C for 24 hours, and weighing after cooling (**Fig. 3.6d**). The concentration is computed using the equation,

$$\boldsymbol{SC = \frac{(M_f - M_i)}{V} \bullet 1000^2} \qquad (3.2)$$

where ***SC*** is sediment concentration (mg/L), $\boldsymbol{M_f}$ is weight of filter paper and sample after oven drying (g), $\boldsymbol{M_i}$ is weight of the filter before sample filtration (g), and ***V*** is volume of filtered water sample (mL).

The monitored data includes 1089, 1258 and 1159 data sets for Mima, Nara and Hiromi rivers, respectively. The differences of number of the monitored data are due to data logger and equipment breakdown and missing/unaccountable data.

## 3.3 Data Analysis Procedure

The data were analyzed using graphical, mathematical, and statistical methods (*i.e.* regression and correlation). Temporal variation assessment of the parameters (*i.e.* precipitation, discharge, sediment concentration and sediment discharge) is done by graphical analysis: determining the average and peak values, noting erratic and unusual fluctuations, and making inferences based on the graphs. Sediment load estimation and analysis, on the other hand, was done using a combination of graphical, mathematical, regression and correlation analysis. As discharge and sediment concentration has very poor relationship (a distinguishing characteristic of small rivers in terms of sediment transport), sediment discharge was used to develop the water discharge-sediment load prediction equations.

Sediment discharge is computed using the equation,

$$\boldsymbol{SD = (SC \bullet Q) \bullet \frac{3600}{1000^2}} \qquad (3.3)$$

where ***SD*** is sediment discharge (kg/hr), ***SC*** is sediment concentration (mg/L), and ***Q*** is water discharge ($m^3$/s).

Two approaches or models were used to analyze the data leading to the derivation of water discharge-sediment load relation: the power and detransformed logarithmic function models which are done using non-linear (NLLS) and linear least square (LLS) regression methods. Analysis was done when data are stratified, that is, grouping the discharge in appropriate classes and using the mean values of discharge classes and corresponding sediment discharge in the derivation of prediction equation (Jansson, 1992; Walling and Webb, 1981). Analysis was also performed when data are seasonally-grouped, that is, representing the four seasons, *i.e.* spring, summer, fall and winter. Using two regression model functions, with and without stratification, and with or without seasonal grouping, a total of 10 distinct prediction equations were developed for each river.

The Power Function model regression is done by plotting the discharge values against the corresponding sediment discharge, and using the non-linear least square (NLLS) method to derive a regressed power equation, in the form,

$$SD = aQ^{b} \tag{3.4}$$

where ***SD*** is sediment discharge (kg/hr), ***Q*** is water discharge ($m^3$/s), and ***a***, ***b*** are regression constants. The Detransformed Logarithmic Function model is done by plotting the means of the logarithms of the discharge against sediment load in a normal scale. Then, using linear least square (LLS) regression method, the water discharge-sediment load relation equation is derived, in the form,

$$LogSD = Loga + bLogQ \tag{3.5}$$

which can be retransformed (back-transformed) to power equation, in the form,

$$SD = 10^{\log a} Q^{b} \tag{3.6}$$

The correlation and test for reliability of prediction models and significant difference between variables were done using some statistical tools. The predictive capability of the developed prediction models is determined by the *Nash-Sutcliffe Model Efficiency Coefficient* (popularly used to describe the predictive accuracy of hydrological models), given as,

$$E = 1 - \frac{\sum_{t=1}^{T}(SD_o^t - SD_m^t)^2}{\sum_{t=1}^{T}(SD_o^t - \overline{SD_o})^2} \tag{3.7}$$

where ***E*** is Nash-Sutcliffe coefficient, $SD_o$ is observed sediment discharge, $SD_m$ is modeled sediment discharge, $SD_o^t$ , $SD_m^t$ are observed and modeled SD at time *t*, and $\overline{SD_o}$ is mean observed sediment discharge. The numerator and denominator terms of the Eq. 3.7 represent the residual and data variances, respectively. An efficiency of 1 ($E = 1$) corresponds to a perfect match of modeled to the observed sediment load data. An efficiency of 0 ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model or when the residual variance (described by the nominator in the expression above) is larger than the data variance (described by the denominator).

The correlation of the discharge to the sediment load in each model equation is determined by the *Coefficient of Determination,* $R^2$. The higher the $R^2$, the better is the correlation of discharge and sediment load. The test for any significant difference between the actual and estimated annual sediment load, annual sediment load by different regression analysis methods, and annual sediment load using data stratification and seasonal grouping were done using the non-parametric significance test *Wilcoxon-Mann-Whitney test*. Likewise, the test of significant difference on the accuracy or predictive efficiency of the equations (Nash-Sutcliffe coefficient) to determine the better model for the data was also done by such tests.

A Water Duration Analysis is conducted to explore the possibility of determining the range of discharge which transports the bulk of the sediment, say, at least 90% of the total sediment. The effect of the rice transplanting activities is computed by grouping the data into rice (RTS) and non-rice transplanting season (NRTS), performing regression analysis on the data and using the derived sediment curves on the rice transplanting season data.

## 3.4 Results and Discussion

### 3.4.1 Discharge and Suspended Sediment Characteristics

#### 3.4.1.1 River discharge characteristics and temporal trend

The discharge in the M river catchment generally follows the event, monthly and seasonal patterns of precipitation (**Fig. 3.7**). It is relatively high during the months of March, June-July and September-October which are characterized by high precipitation events and/or regular typhoon occurrences. The Year 2011 is the wettest year during the monitoring period with more than 500 mm of precipitation during the months of June and September, apparently affecting the water yield monthly and seasonal trends. The Year 2010 is also a high-precipitation year with numerous typhoons, hence, also lot of flood occurrences.

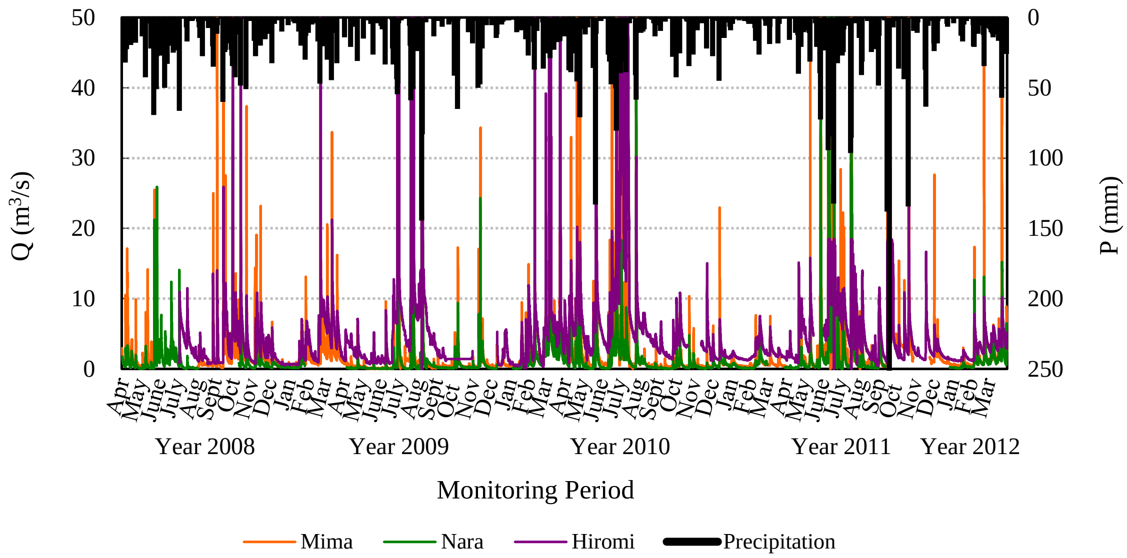



Figure 3.7: Daily time series of precipitation and discharge

The monthly data of water yield of the three rivers shows a tri-modal distribution with highest peak on June and minor peaks on March and October (**Fig. 3.8**). The seasonal trend comes in a cycle reaching peak during summer and gradually falling towards winter, with the seasonal mean discharge complementing the water yield temporal distribution. This is reflected in the seasonal mean discharge of the rivers where it is high during spring, reached its highest on summer and gradually decreases towards winter (**Table 3.2**). The highest discharge value occurs during either spring or summer.

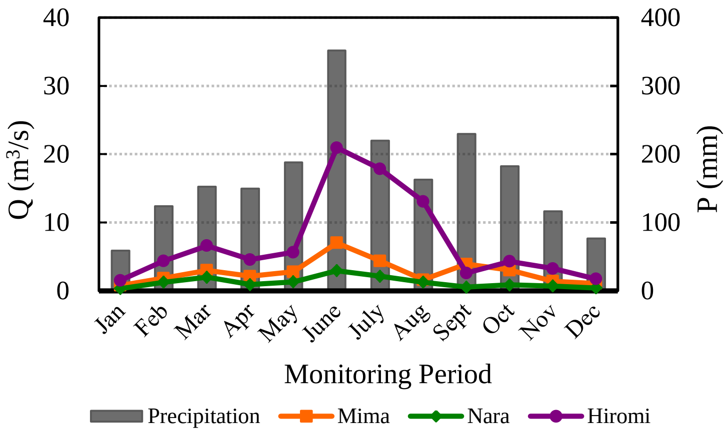



Figure 3.8: Average monthly precipitation and discharge

Table 3.2: Descriptive statistics of discharge using aggregated and seasonal data (Q, $m^3/s$)

| River/Season | Min. | Median | Max. | Mean | CV (%) | Sk | Kurt |
|---|---|---|---|---|---|---|---|
| Mima: Aggregate | ***0.01*** | ***0.79*** | ***93.5*** | ***2.74*** | ***270*** | ***9.1*** | ***108*** |
| Spring | 0.01 | 0.95 | 93.5 | 2.49 | 298 | 8.9 | 93 |
| Summer | 0.01 | 0.87 | 55.4 | 2.86 | 259 | 5.2 | 29 |
| Fall | 0.11 | 0.58 | 30.2 | 1.68 | 186 | 5.2 | 35 |
| Winter | 0.31 | 0.77 | 13.1 | 1.24 | 122 | 4.8 | 30 |
| Nara: Aggregate | ***0.01*** | ***0.42*** | ***36.5*** | ***1.22*** | ***226*** | ***6.0*** | ***47*** |
| Spring | 0.01 | 0.56 | 21.1 | 1.37 | 215 | 4.5 | 26 |
| Summer | 0.01 | 0.61 | 36.5 | 2.08 | 214 | 4.2 | 21 |
| Fall | 0.03 | 0.23 | 9.0 | 0.54 | 188 | 5.2 | 33 |
| Winter | 0.03 | 0.46 | 7.9 | 0.72 | 132 | 4.0 | 22 |
| Hiromi: Aggregate | ***0.20*** | ***3.20*** | ***395*** | ***7.20*** | ***416*** | ***12.1*** | ***195*** |
| Spring | 0.84 | 3.97 | 395 | 12.21 | 414 | 8.1 | 88 |
| Summer | 0.75 | 4.75 | 351 | 16.89 | 265 | 6.6 | 54 |
| Fall | 0.18 | 2.78 | 322 | 7.01 | 406 | 9.3 | 90 |
| Winter | 0.20 | 1.94 | 24 | 2.67 | 194 | 3.4 | 21 |

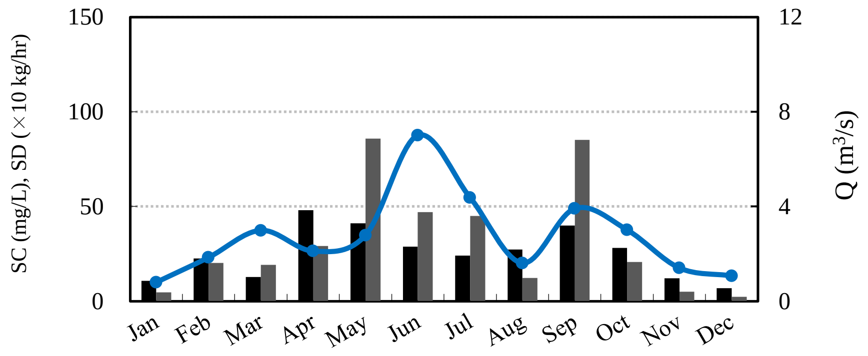
The discharge data distributions, considering both aggregate and seasonal data, show high measures of dispersion (CV), skewness (Sk) and peakedness (Kurt). The highest dispersion is during spring and lowest during winter, although all seasons have also relatively high dispersion mainly due to many low flow and few but extremely high peak discharge values.All distributions are skewed to the right (Skewness, Sk>0) and has a very sharp peak (Kurtosis, Kurt>0), reflecting the effect of infrequent very high storm events. This can also be inferred from the median and mean values which are much closer to the minimum discharge values. The values of skewness and kurtosis also reflects the size of the rivers, as Nara river (the smallest in terms of watershed area) has the lowest and Hiromi river (the biggest watershed area) has the highest value of such statistical parameters.

#### 3.4.1.2 Suspended sediment characteristics and temporal trends

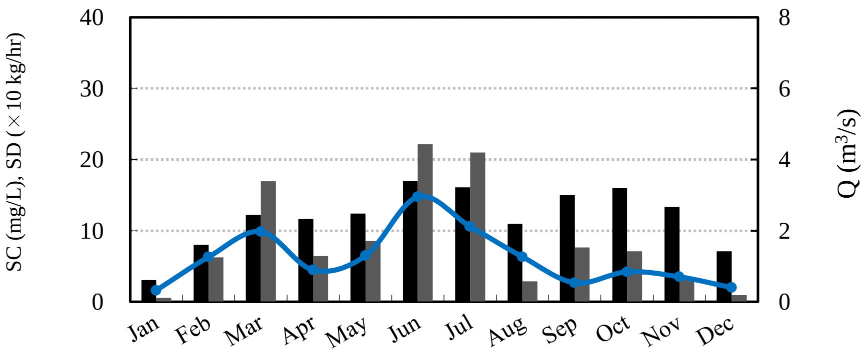
The monthly temporal trend of SC and SD (**Fig. 3.9**) shows inconsistencies with respect to Q, particularly in some months within the March-September period. This could apparently be attributed to the effect of precipitation and flood events corresponding to discharge of sediment-laden drainage and effluents from the agricultural which particularly causes impact to SC at low to average flow. The middle to last week of March marks the start of the land preparation, especially in rice paddy fields. The activity peaks during April and May, and continues until June at Mima river watershed (*refer to* **Table 3.1**)

The three rivers showed generally high values of SC and SD during March-September period, but somehow different in monthly temporal trend. For SC, the rivers showed high values on April-June/July and September-November period, which can be attributed to the effect of both rainfall and flood events causing natural land surface erosion and to the sediment-laden discharge and effluents from agricultural areas (especially rice paddy) during land preparation and agricultural production season. For SD, Mima river has relatively high values during May, June July and September; Nara river on high values on March, June and July; and Hiromi river has high values on June, July and September (**Fig. 3.9**). Thus, it could be inferred that the months of June, July and September represent the months with the higher SD values.

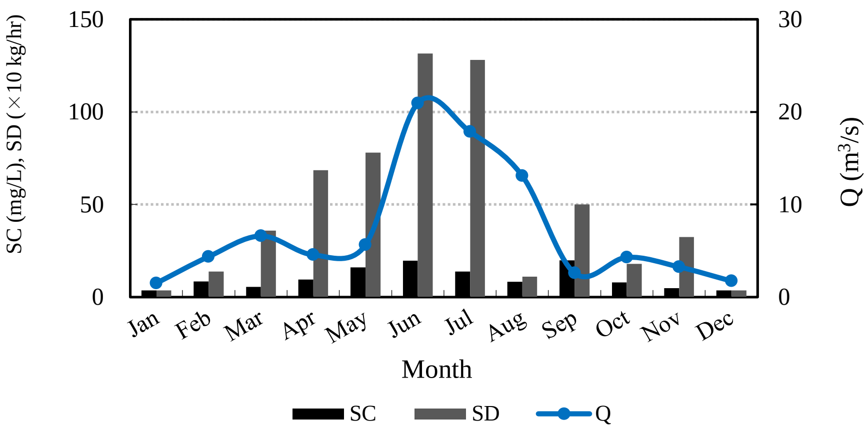
Moreover, monthly variation of SC shows multi-modal distribution with February-April-September for Mima river, March-June-October for Nara river and February-June-September for Hiromi river, representing the months with high SC values. The month of April and May, although doesn’t have high Q, have disproportionately high SC and SD values which could be due to the agricultural activities. The seasonal variation shows the same trend for Mima and Nara rivers which is relatively high on spring, slightly lower on summer, highest on fall and decreases on winter; while for Hiromi river, it peak on summer, slightly decreases on fall and further decreases on winter (**Fig. 3.10**).




a. Mima River

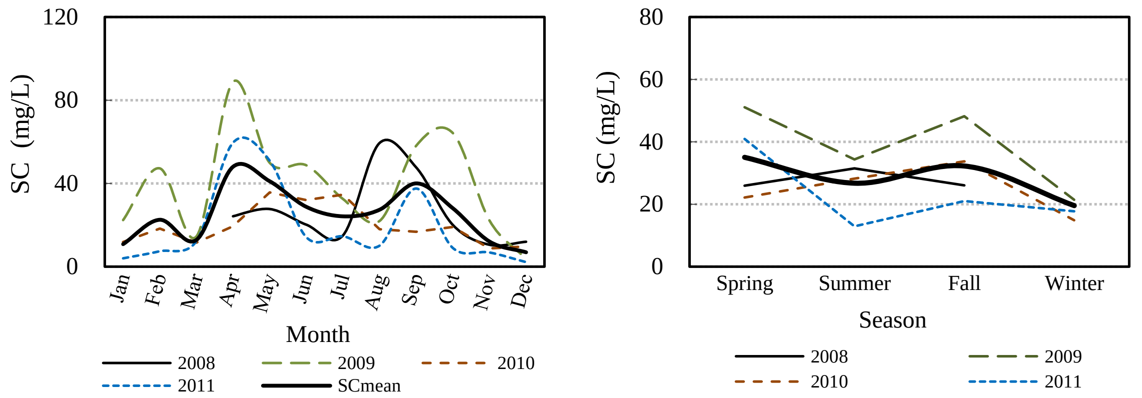



b. Nara River

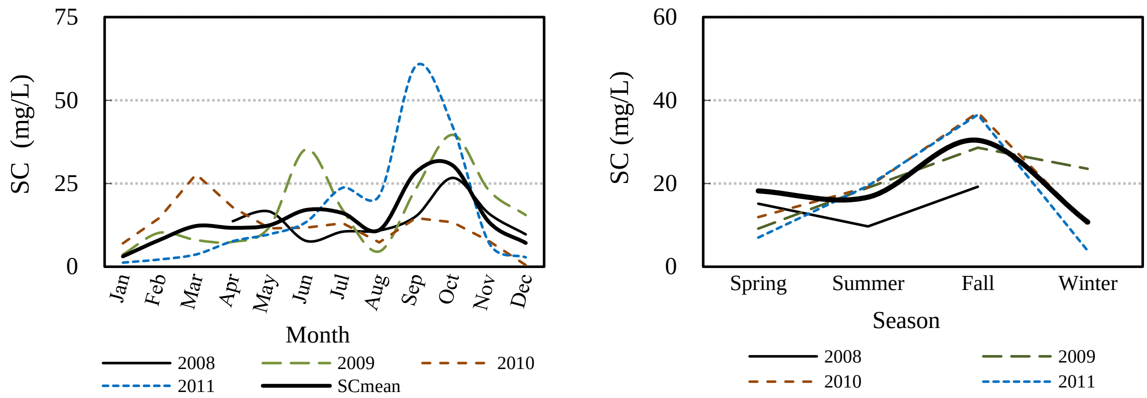



c. Hiromi River

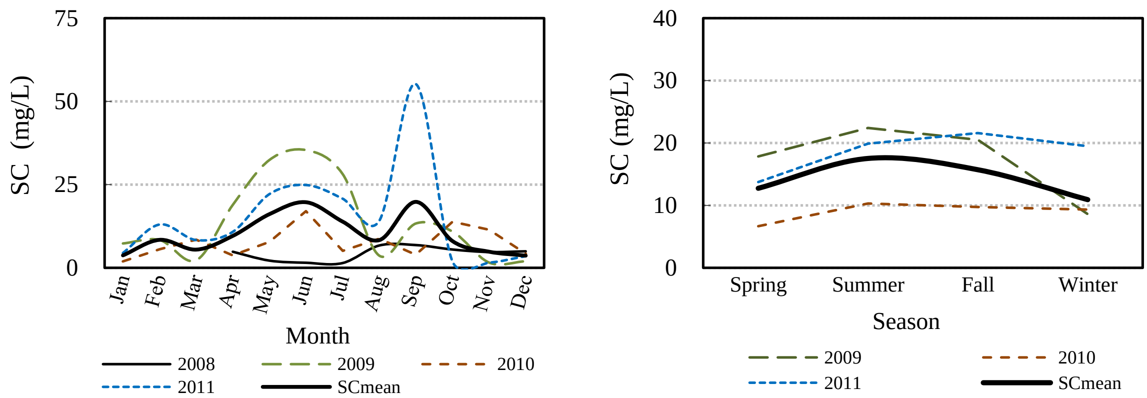
Figure 3.9: Average monthly discharge, sediment concentration and sediment discharge




a. Mima River




b. Nara River




c. Hiromi River

Figure 3.10: Average monthly and seasonal sediment concentration

Table 3.3: Descriptive statistics of suspended sediment concentration (SC, mg/L) and suspended sediment discharge (SD, kg/hr) using aggregated and seasonal data

| River/Season | Min. | Median | Max. | Mean | CV (%) | Sk | Kurt |
|---|---|---|---|---|---|---|---|
| ***Mima*, SC**:Aggregate | ***0*** | ***15*** | ***395*** | ***26*** | ***125*** | ***3.4*** | ***20*** |
| Spring | 0 | 23 | 217 | 36 | 105 | 2.0 | 5 |
| Summer | 2 | 18 | 169 | 28 | 93 | 2.2 | 7 |
| Fall | 0 | 15 | 395 | 25 | 154 | 4.8 | 35 |
| Winter | 0 | 7 | 143 | 14 | 148 | 3.0 | 11 |
| **SD**:Aggregate | ***0*** | ***13*** | ***58469*** | ***357*** | ***357*** | ***17.1*** | ***338*** |
| Spring | 0 | 63 | 58469 | 477 | 766 | 14.9 | 233 |
| Summer | 2 | 61 | 16345 | 566 | 380 | 5.7 | 33 |
| Fall | 0 | 37 | 42989 | 299 | 934 | 15.1 | 228 |
| Winter | 0 | 22 | 3288 | 91 | 325 | 7.7 | 69 |
| ***Nara*, SC**:Aggregate | ***0*** | ***10*** | ***220*** | ***14*** | ***131*** | ***4.4*** | ***36*** |
| Spring | 0 | 8 | 75 | 13 | 99 | 2.0 | 5 |
| Summer | 0 | 10 | 120 | 15 | 96 | 2.0 | 10 |
| Fall | 0 | 15 | 220 | 23 | 125 | 3.8 | 20 |
| Winter | 0 | 3 | 93 | 7 | 166 | 3.6 | 18 |
| **SD**:Aggregate | ***0*** | ***12*** | ***15881*** | ***109*** | ***586*** | ***18.0*** | ***397*** |
| Spring | 0 | 13 | 4390 | 113 | 306 | 7.9 | 84 |
| Summer | 0 | 21 | 15881 | 200 | 546 | 11.3 | 147 |
| Fall | 0 | 15 | 1064 | 54 | 254 | 5.4 | 33 |
| Winter | 0 | 2 | 1284 | 28 | 396 | 8.1 | 78 |
| ***Hiromi*, SC**:Aggregate | ***0*** | ***5*** | ***260*** | ***10*** | ***190*** | ***5.7*** | ***53*** |
| Spring | 0 | 5 | 100 | 11 | 139 | 2.3 | 7 |
| Summer | 0 | 5 | 180 | 13 | 167 | 3.4 | 17 |
| Fall | 0 | 3 | 260 | 10 | 237 | 7.1 | 63 |
| Winter | 0. | 3 | 50 | 5 | 161 | 3 | 12 |
| **SD**:Aggregate | ***0*** | ***49*** | ***214762*** | ***906*** | ***1036*** | ***18.4*** | ***366*** |
| Spring | 0 | 107 | 214762 | 1613 | 920 | 13.9 | 196 |
| Summer | 0 | 100 | 145314 | 1139 | 807 | 15.1 | 234 |
| Fall | 0 | 45 | 115018 | 874 | 891 | 13.6 | 195 |
| Winter | 0 | 7 | 3415 | 68 | 364 | 10.8 | 139 |

While SD appear to be indicative of the size of river watershed area, SC is not as Hiromi river appears to have lower SC values than Mima and Nara rivers although it is 3 time and 6 times as large as the two rivers, respectively. This can be attributed to lower proportion of cultivated areas, particularly rice paddy (**Table 3.1**). On the average, the SC value of Hiromi river is just 40% and 70% of the SC values while its SD values is 250% and 630% of the SD values of Mima and Nara rivers, respectively (*refer to* **Table 3.3**).

The SC has a wide range of values, that is 0~395 mg/l for Mima river, 0~220 mg/L for

Nara river, and 0~260 mg/L for Hiromi river—considering aggregate data (**Table 3.3**). The highest measured SC value occurred during Fall, during a high rainfall and flood event. The wide range translates to a high coefficient of variation (CV) at 125%, 131% and 190% for Mima, Nara and Hiromi rivers, respectively, considering aggregate data. These CV values, however, are much lower compared to the CV values of many big rivers as it may vary up to three or five degrees of magnitude (Iadanza and Napolitano, 2006; Sadeghi *et al.*, 2008; Hu *et al.*, 2011). The SC data distribution is slightly skewed to the right (as shown by mean > median) and slightly peaked as effected by many low to average and few extremely high values. In fact, at least 80% of the SC values are below the mean, as indicated also by the median being so close to the minimum values.

Nil values accounted approximately 5% of the recorded SC values. The occurrence is highest during Winter (20% of the total seasonal data) which is a period of low and clear flow, as well as no agricultural activities. The occurrence of nil SC could be attributed to the fact that the rivers are small and unlike big rivers which usually contain abundant suspended materials for transport, it often depend on episodic contribution from upland areas (Thomas, 1988).

The data on computed suspended sediment discharge (SD) shows a very high dispersion (CV=357-1036), skewness (Sk=17.1-18.4), and kurtosis (K=338-397), showing the compounded effect of Q and inconsistent SC (**Table 3.1**). The range is extremely high during Spring (due to onset of agricultural activities, *i.e.* land preparation) and during Fall (due to high storm events) while it is very low during Winter. The seasonal pattern of SD range and mean values is not consistent to that of both Q and SC, *i.e.* bi-modal temporal pattern: highest during Spring, decreases during Summer, increases on Fall, and decreases towards Winter.

Similar to SC values, SD values has some extremely high values while most values are low, as indicated by median and mean values which much closer to the minimum value. The occurrence of extreme values could be attributed to the same reason as that of SC values.

A closer perusal of the time series data shows that suspended sediment concentration has irregular peaks disproportionate to that of discharge, especially during spring and summer seasons which correspond to the agricultural production season, particularly rice production (**Fig. 3.10**). It apparently reflects the effect of agricultural activities, especially the drainage from rice paddy fields. As discussed earlier, SC did not follow the monthly and seasonal patterns of discharge (**Fig. 3.9**). It is high during April which does not correspond to a high water yield, though a high value in September corresponds to a high water yield. The mean seasonal value is highest during spring or summer and tends to decrease towards Winter (**Table 3.3**).

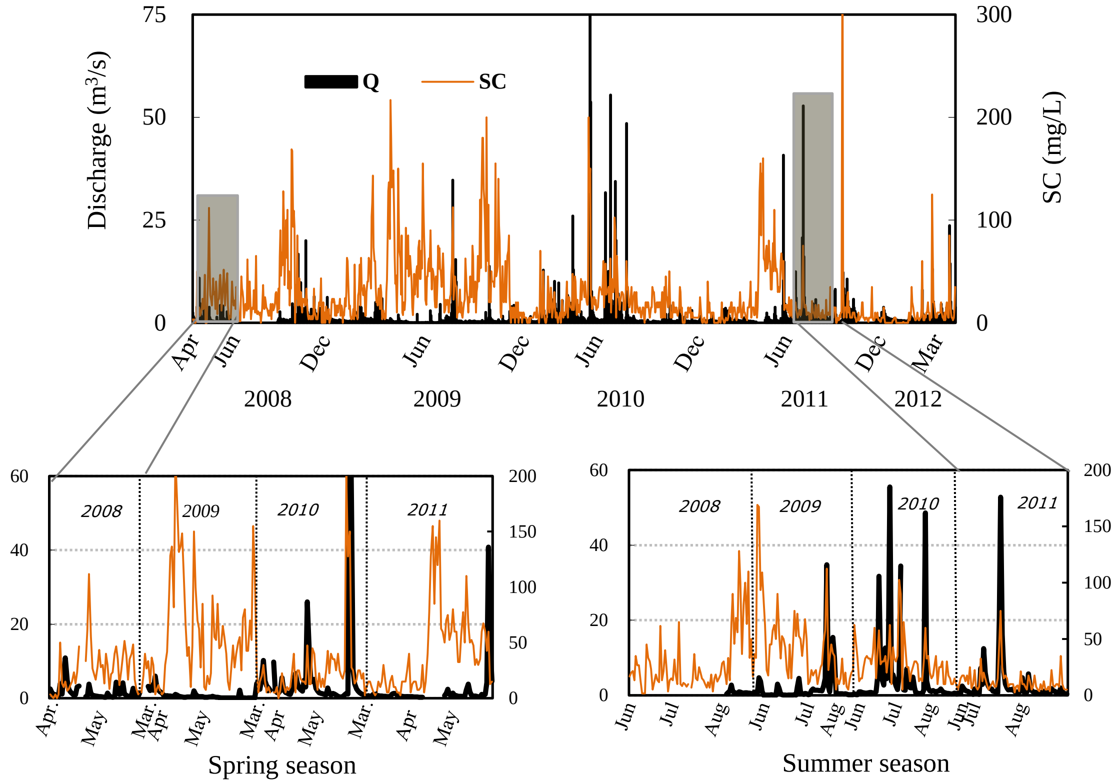



Figure 3.11: Mima river's time series of instantaneous discharge and sediment concentration, and highlighted portions for agricultural production season (spring and summer)

### 3.4.1.3 Suspended sediment load temporal distribution

The observed annual total suspended sediment load is 3,264×$10^3$ kg in Mima river, 811×$10^3$ kg in Nara river, and 5,126×$10^3$ kg in Hiromi river (**Table 3.4**).

The remarkably high amount during 2010 was contributed by the several torrential rainfall occurrences during the months of May-July and aggravated by the effluents and drainage from agricultural areas during the peak of land preparation and crop growing season. The excessively high rainfall amount during June and September 2011 resulted in the highest monthly water yield, yet did not translate to high suspended sediment load due, primarily due to few occurrences and out of time from the peak of agricultural activities. This lead to a conjecture that for the Mima river, high storm events doesn't necessarily results significantly to high total suspended sediment load (*refer to* **Fig.3.7**, **3.8** and **3.9**).

The suspended sediment load follows an erratic pattern when considered during the whole monitoring period. However, it is generally high during the April-July period and drastically low during November-January period (**Fig. 3.12**). Considering the average monthly suspended sediment load values, the load started to increase on April, reaching its peak during May-July, and decreases towards December, and slightly increases during

September-October period. This pattern could be attributed to the start of land preparation during April (or middle of March) particularly in rice paddy areas, continuation of land preparation and peak of agricultural activities during May-July and occurrences of many rainfall events, some of which are torrential, and the rainy or typhoon season during September-October. However, since storm event and typhoons are not time constant, it was exhibited at least few times in any other months, *i.e.* February 2009, November 2009 and December 2010.

Table 3.4: Average monthly and seasonal sediment load (SL) and water yield (QY) using observed data

| Month/Season | Mima | | Nara | | Hiromi | |
|---|---|---|---|---|---|---|
| | SL ($\times 10^3$ kg) | QY ($\times 10^7$ $m^3$) | SL ($\times 10^3$ kg) | QY ($\times 10^7$ $m^3$) | SL ($\times 10^3$ kg) | QY ($\times 10^7$ $m^3$) |
| January | 34 | 2.1 | 4 | 0.9 | 33 | 4.0 |
| February | 135 | 4.5 | 42 | 2.5 | 92 | 10.6 |
| March | 147 | 8.0 | 126 | 4.6 | 367 | 17.7 |
| April | 260 | 5.5 | 50 | 2.4 | 578 | 11.8 |
| May | 606 | 7.5 | 63 | 3.4 | 861 | 25.1 |
| June | 321 | 18.2 | 156 | 7.9 | 1704 | 54.3 |
| July | 909 | 11.7 | 211 | 5.7 | 735 | 47.5 |
| August | 90 | 4.3 | 21 | 3.4 | 97 | 35.0 |
| September | 614 | 10.1 | 55 | 1.4 | 77 | 6.7 |
| October | 154 | 8.1 | 53 | 2.2 | 186 | 11.5 |
| November | 36 | 3.6 | 23 | 1.9 | 366 | 8.4 |
| December | 17 | 2.9 | 7 | 1.1 | 32 | 4.6 |
| **Spring** | 954 | 21 | 239 | 10 | 1805 | 55 |
| **Summer** | 1320 | 34 | 388 | 17 | 2536 | 137 |
| **Fall** | 804 | 22 | 131 | 6 | 628 | 27 |
| **Winter** | 186 | 9 | 53 | 4 | 157 | 9 |
| Annual TOTAL | **3264** | **86** | **811** | **37** | **5126** | **227** |

The most sediment-laden month is July for Mima and Nara rivers and June for Hiromi river, accounting 28%, 26% and 33% of the annual total suspended sediment load with corresponding 40% , 15% and 24% of the water yield, respectively. Among the seasons, summer has the bulk of the annual sediment load with 40%, 40% and 49%, corresponding to a water yield of 40%, 46% and 60% for the three rivers, respectively (**Table 3.4**). On the other hand, winter has only 6%, 7% and 3% of the annual sediment load. Moreover, spring has relatively higher sediment load the fall despite a proportionately smaller difference in water yield.

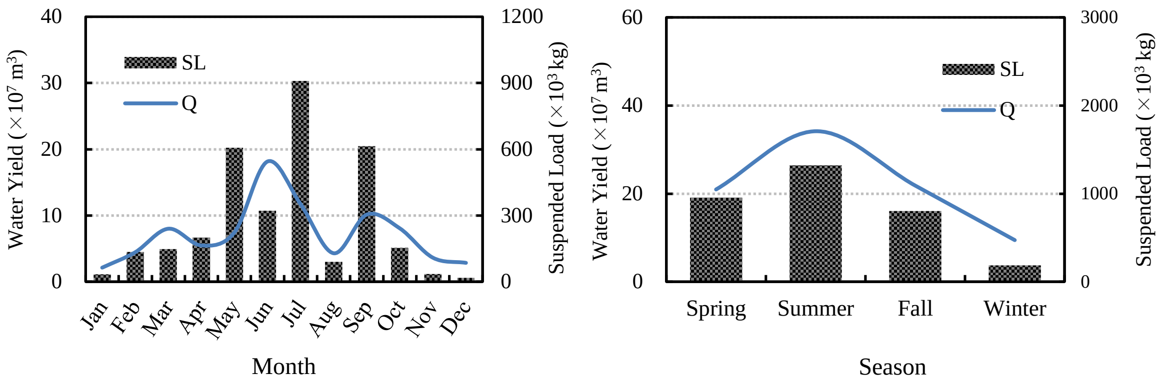
The temporal trend of sediment load shows spring and summer season taking the bulk of the transported sediment in the rivers, particularly during the periods March-July (**Fig. 3.12**). Specifically, the sediment load increases towards summers and decreases towards winter. On the other hand, the monthly temporal trend shows multiple trend on the SL variations but, generally, it increases towards June or July and decreases towards December, although a slight increase happens during the months of September or October.

The inequality of the water yield and suspended sediment load is represented and highlighted by the monthly and seasonal hysteretic loop pattern (**Fig. 3.13**). Hysteretic loops or patterns have been used to study suspended sediment dynamics during floods (Williams, 1989; Sadeghi *et al.*, 2008) and, in this case, it is applied to both monthly and seasonal values to elucidate general patterns of suspended sediment transport. The factors affecting these patterns include land preparation and start of agricultural production season during Spring, agricultural productions season and rainy season during Summer, end of agricultural production and rainy season during Fall, and absence of both factors during Winter. Furthermore, considering natural soil erosion, the low suspended sediment load during Winter could be associated with the phenomenon of sediment preparation (Walling and Webb, 1981; Gao and Josefson, 2012).

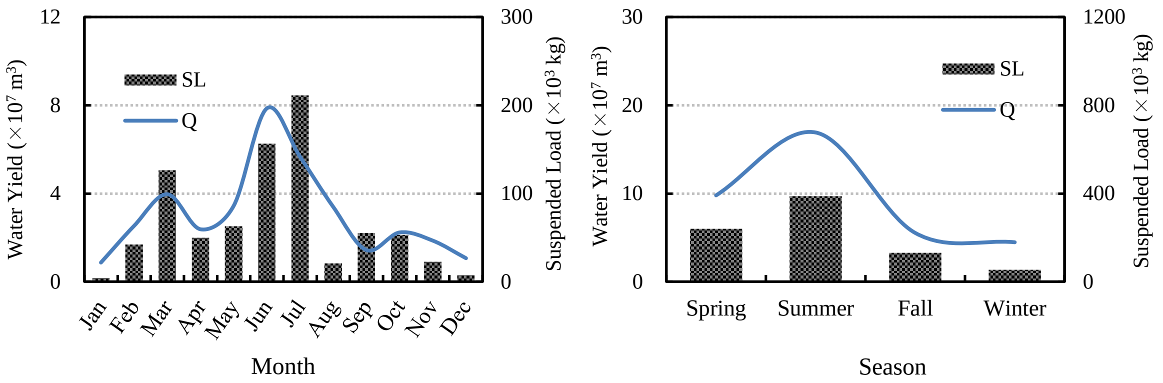
The seasonal suspended sediment load pattern generally corresponds with that of the water yield but the monthly hysteretic pattern is rather erratic (**Fig. 3.13**). The monthly hysteresis generally follows a counter-clockwise pattern in Mima and Nara river but clockwise in Hiromi river. It shows a significant change in the suspended sediment load from April to August, particularly between the months of May-June-July-August. The significant change reflects the increasing agricultural activities (land preparation and rice planting), as well as the effect of rainy season. The other months (September to March) has a rather insignificant change in both sediment load and water yield.

In Mima and Nara rivers, the sediment load and water yield reaches its peak on July despite decreasing agricultural activities which is a manifestation of the significant effect of several episodic floods especially those occurring in the year 2010 and 2011.

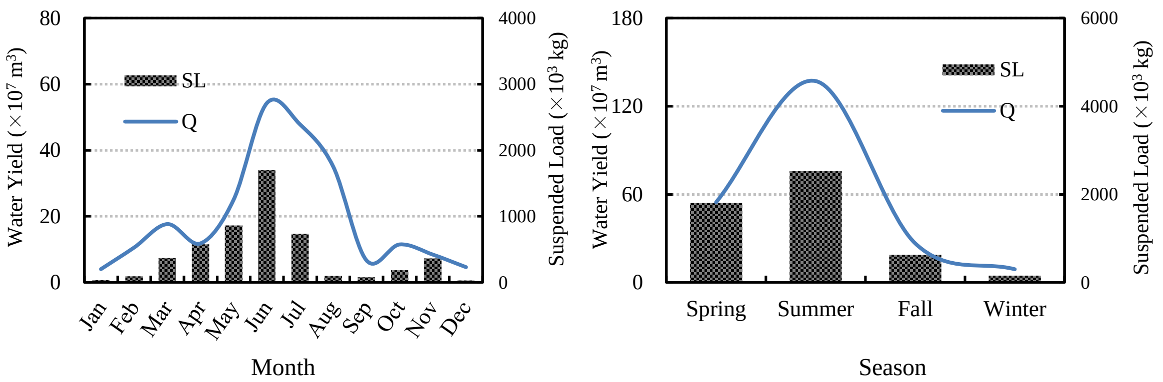
While the monthly sediment load shows an erratic pattern when considered during the whole monitoring period, the seasonal sediment load pattern shows a rather clear clockwise cyclic pattern: high during Spring, attain its peak during Summer, decreases during Fall and hit its lowest during Winter. On the average, almost half of the annual sediment load (46%) is delivered during Summer and almost a third during spring (31%). This totals to 77%, leaving only a quarter of the suspended sediment (22%) delivered during the other two succeeding seasons (*refer to* **Table 3.4**).




a. Mima River

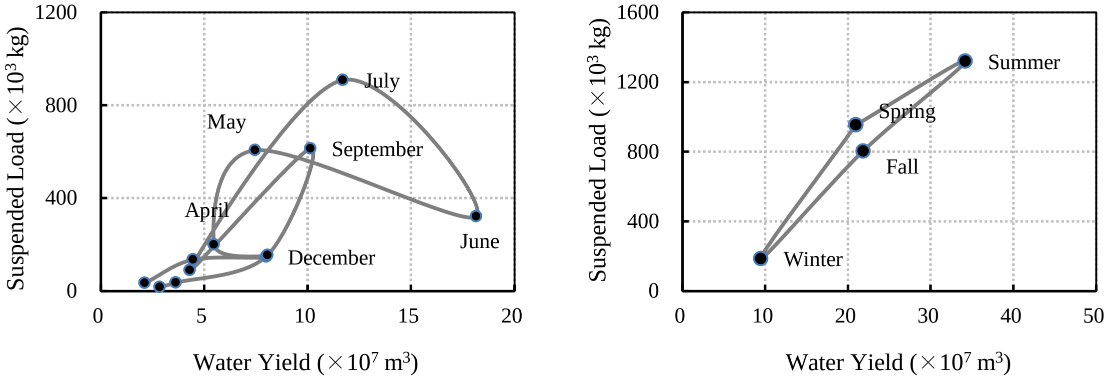



b. Nara River

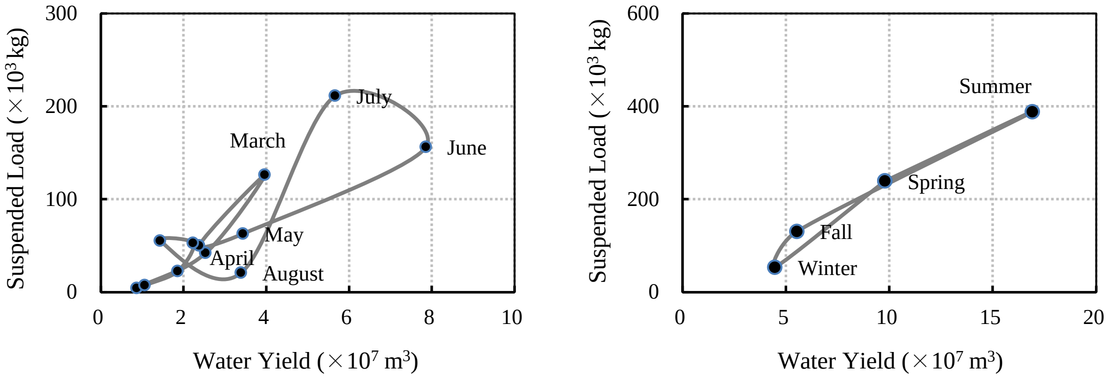



c. Hiromi River

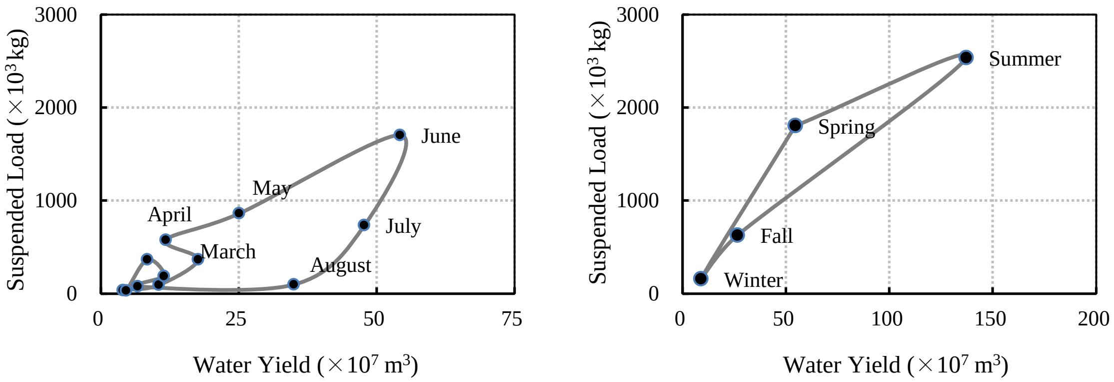
Figure 3.12: Monthly and seasonal water yield and sediment load




a. Mima River




b. Nara River




c. Hiromi River

Figure 3.13: Monthly and seasonal suspended sediment load hysteresis loop

### 3.4.2. Regression Analysis and Suspended Sediment Rating Curve

#### 3.4.2.1 Sediment concentration or sediment discharge

The preliminary analysis using the optimum function model ($2^{nd}$ degree polynomial) reveals very poor Q-SC correlation in the three rivers (**Fig. 3.14**), complementing the result of temporal trend analysis in the previous section which found that SD is more proportionate to Q than SC to Q.

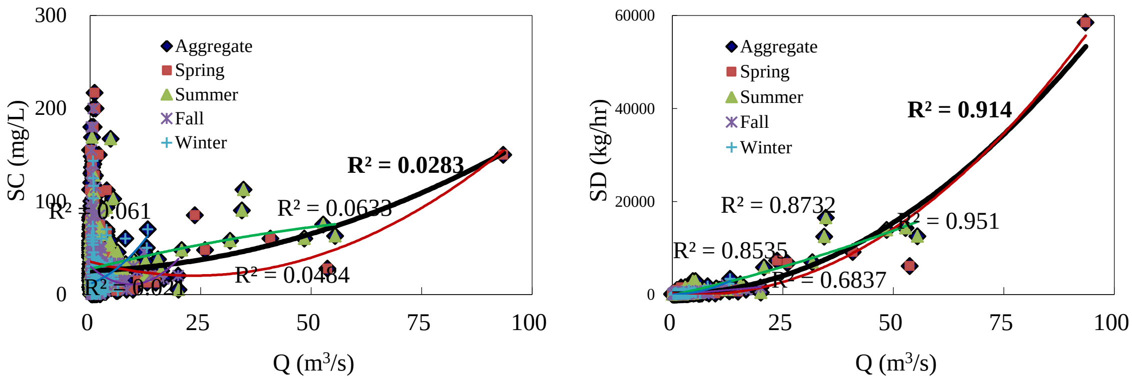
The developed optimum regression lines show statistically insignificant coefficients of determination, both using aggregate ($R^2$=0.0283~0.0738) and in seasonal clusters ($R^2$=0.0484~0.2968), making it statistically unsuitable for regression analysis (**Fig. 3.14**). This is one difference of smaller rivers from big rivers draining agriculturally productive areas, raising the uncertainty of adapting the sediment load regression analysis methods commonly used for big rivers. In fact, most sediment estimation studies dealing with big rivers, irrespective of watershed characteristics and land uses, used SC to derive the sediment rating curve since SC has a good correlation with Q (Batalla and Sala, 1994; Jansson, 1996; Iadanza and Napolitano, 2006; Achite and Ouillon, 2007; Hu *et al.*, 2011). Moreover, most suspended sediment estimation studies utilized SC to derive the sediment rating curve, as it dealt with big rivers where SC has good correlation, even logarithmically transforming the values to normalized errors due to high scatter of data (Ferguson, 1986; Crawford, 1991; Jansson, 1996; Asselman, 2000; Hu *et al.*, 2011).

On the other hand, the statistically significant and better correlation of Q-SD necessitate the use of suspended sediment discharge in the derivation of sediment rating curve during regression analysis, hence, the model equation $SD=aQ^b$. Although few, there are literatures on suspended sediment estimation studies where SD is used to derive the sediment rating curve, like the studies conducted by Achite and Ouillon (2007) and Restrepo and Kjerfve (2000).

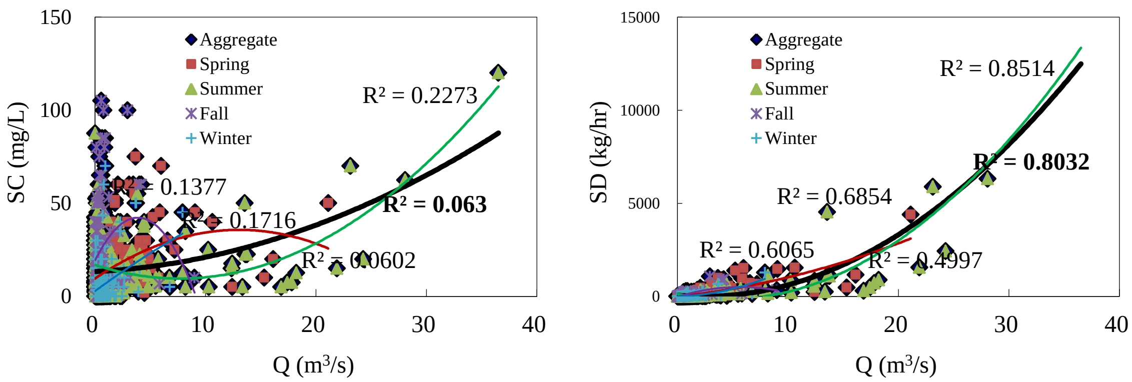
#### 3.4.2.2 Without or with data stratification

The preliminary analysis conducted found that the power function model used to represent sediment transport would not be applicable to the collected/monitored data due to the occurrences of nil sediment concentration values. Using the present data, the optimum model equation is a polynomial function model which, despite having a relatively high factor correlation and model efficiency coefficients, results to significantly underestimated sediment load in low flows and overestimated sediment load in high flows. The underestimation during low flow even results to many improbably negative sediment load values.

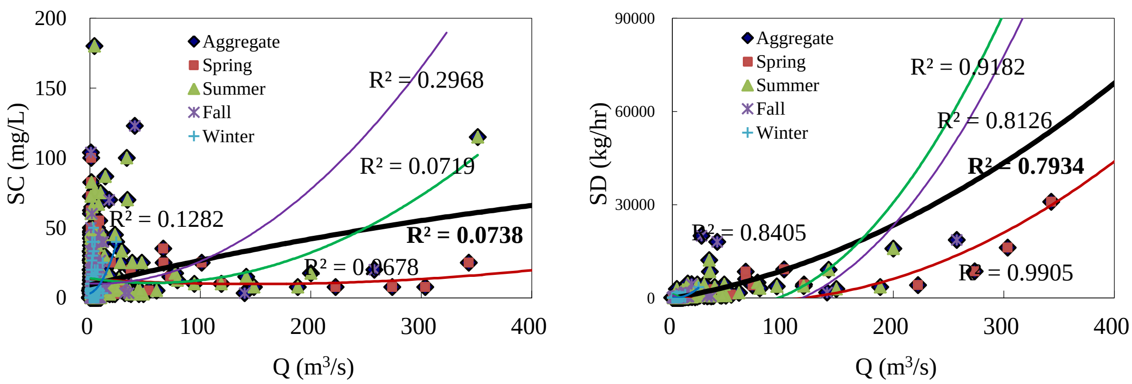
In order to adapt the power function model while using all monitored data, including the nil values, the concept of data stratification or using mean class values is adapted.




a. Mima River




b. Nara River

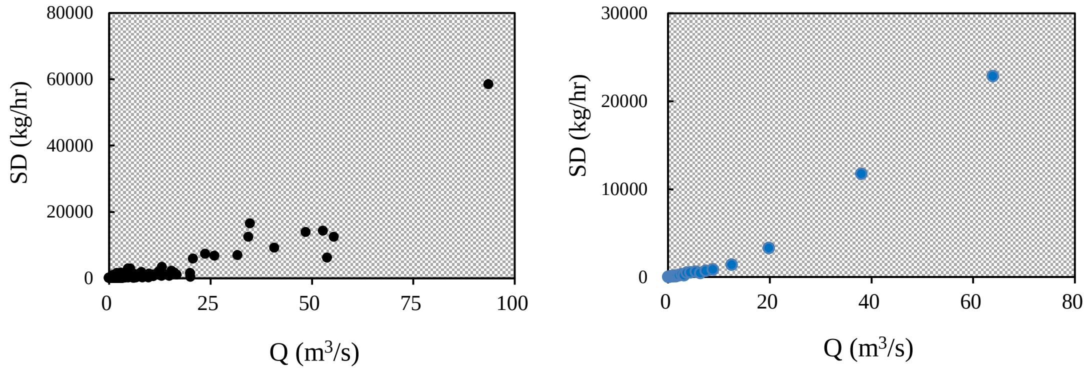



c. Hiromi River

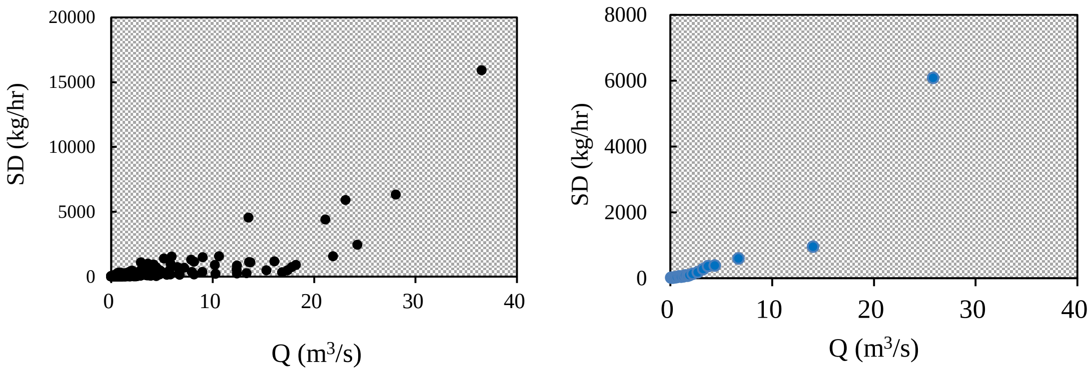
Figure 3.14: Q-SC and Q-SD correlations using 2nd order polynomial regression

Table 3.5: Discharge classes for aggregated and seasonally-clustered data

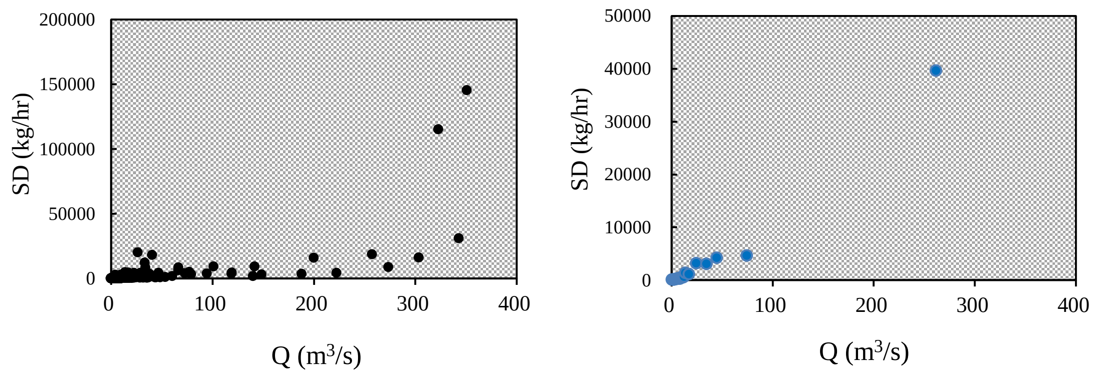
| River | Aggregate Data | Seasons | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter |
| Mima | 0.0~0.2 | 0.0~0.2 | 0.0~0.2 | 0.0~0.2 | 0.0~0.4 |
| ($m^3/s$) | 0.2~0.4 | 0.2~0.4 | 0.2~0.4 | 0.2~0.3 | 0.4~0.5 |
| | 0.4~0.6 | 0.4~0.6 | 0.4~0.6 | 0.3~0.4 | 0.5~0.6 |
| | 0.6~0.8 | 0.6~0.8 | 0.6~0.8 | 0.4~0.5 | 0.6~0.7 |
| | 0.8~1.0 | 0.8~1.0 | 0.8~1.0 | 0.5~0.6 | 0.7~0.8 |
| | 1.0~1.25 | 1.0~1.25 | 1.0~1.25 | 0.6~0.7 | 0.8~0.9 |
| | 1.25~1.50 | 1.25~1.50 | 1.25~1.50 | 0.7~0.8 | 0.9~1.0 |
| | 1.50~1.75 | 1.5~2.0 | 1.50~1.75 | 0.8~1.0 | 1.0~1.25 |
| | 1.75~2.0 | 2.0~2.5 | 1.75~2.0 | 1.0~1.25 | 1.25~1.50 |
| | 2.0~2.5 | 2.5~3.0 | 2.0~2.5 | 1.25~1.50 | 1.50~1.75 |
| | 2.5~3.0 | 3.0~4.0 | 2.5~3.0 | 1.5~2.0 | 1.75~2.0 |
| | 3.0~3.5 | 4.0~5.0 | 3.0~4.0 | 2.0~3.0 | 2.0~2.5 |
| | 3.5~4.0 | 5.0~10 | 4.0~5.0 | 30~10 | 2.5~3.0 |
| | 4.0~5.0 | 10~20 | 5.0~10 | 10~ | 3.0~4.0 |
| | 5.0~6.0 | 20~40 | 10~20 | | 4.0~5.0 |
| | 6.0~7.0 | 40~ | 20~30 | | 5~10 |
| | 7.0~8.0 | | 30~ | | 10~ |
| | 8.0~10 | | | | |
| | 10~15 | | | | |
| | 15~30 | | | | |
| | 30~50 | | | | |
| | 50~ | | | | |
| Nara | 0.0~0.2 | 0.0~0.1 | 0.0~0.1 | 0.0~0.1 | 0.0~0.1 |
| ($m^3/s$) | 0.2~0.4 | 0.1~0.2 | 0.1~0.2 | 0.1~0.2 | 0.1~0.2 |
| | 0.4~0.6 | 0.2~0.3 | 0.2~0.3 | 0.2~0.3 | 0.2~0.3 |
| | 0.6~0.8 | 0.3~0.4 | 0.3~0.4 | 0.3~0.4 | 0.3~0.4 |
| | 0.8~1.0 | 0.4~0.5 | 0.4~0.5 | 0.4~0.6 | 0.4~0.5 |
| | 1.0~1.2 | 0.5~0.6 | 0.5~0.6 | 0.6~1.0 | 0.5~0.6 |
| | 1.2~1.4 | 0.6~0.7 | 0.6~0.8 | 1.0~2.0 | 0.6~0.8 |
| | 1.4~1.6 | 0.7~0.8 | 0.8~1.0 | 2.0~5.0 | 0.8~1.0 |
| | 1.6~1.8 | 0.8~0.9 | 1.0~2.0 | 5~10 | 1.0~1.25 |
| | 1.8~2.0 | 0.9~1.0 | 2.0~3.0 | 10~ | 1.25~1.5 |
| | 2.0~2.5 | 1.0~1.25 | 3.0~5.0 | | 1.5~2.0 |
| | 2.5~3.0 | 1.25~1.5 | 5~10 | | 2.0~4.0 |
| | 3.0~3.5 | 1.5~2.0 | 10~15 | | 4.0~10 |
| | 3.5~4.0 | 2.0~3.0 | 15~ | | 10~ |
| | 4.0~5.0 | 3.0~5.0 | | | |
| | 5~10 | 5~10 | | | |
| | 10~20 | 10~15 | | | |
| | 20~ | 15~ | | | |
| Hiromi | 0~1 | 0~1 | 0~1 | 0~1 | 0~0.5 |
| ($m^3/s$) | 1~2 | 1.0~1.5 | 1~2 | 1~2 | 0.5~1.0 |
| | 2~3 | 1.5~2.0 | 2~3 | 2~3 | 1.0~1.5 |
| | 3~4 | 2.0~2.5 | 3~4 | 3~4 | 1.5~2.0 |
| | 4~5 | 2.0~3.0 | 4~5 | 4~5 | 2.0~2.5 |
| | 5~6 | 3.0~3.5 | 5~6 | 5~6 | 2.0~3.0 |
| | 6~7 | 3.5~4.0 | 6~7 | 6~7 | 3.0~3.5 |
| | 7~8 | 4~5 | 7~8 | 7~8 | 3.5~4.0 |
| | 8~9 | 5~6 | 8~9 | 8~9 | 4~6 |
| | 9~10 | 6~7 | 9~10 | 9~10 | 6~10 |
| | 10~11 | 7~8 | 10~30 | 10~20 | 10~20 |
| | 11~12 | 8~9 | 30~100 | 20~100 | 20~ |
| | 12~13 | 9~10 | 100~ | 100~ | |
| | 13~15 | 10~15 | | | |
| | 15~20 | 15~40 | | | |
| | 20~30 | 40~100 | | | |
| | 30~40 | 100~ | | | |
| | 40~50 | | | | |
| | 50~100 | | | | |
| | 100~ | | | | |




a. Mima River




b. Nara River




c. Hiromi River

Figure 3.15: Q-SD correlation without and with stratified data

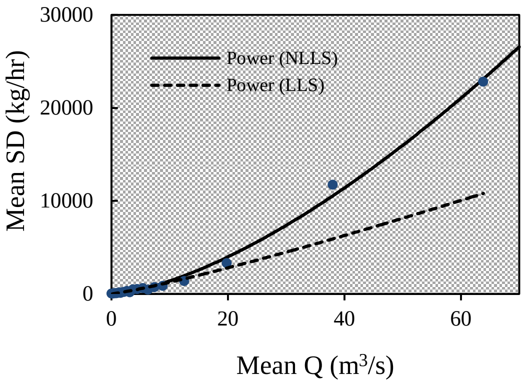
In the data stratification process, the mean values of Q and the corresponding mean SD of the data classes were used in the regression analysis. The stratification procedure involves ranking the discharge data from lowest to highest and a number of appropriate classes were constructed based on the range of discharge and available number of data. Discharge data analysis showed that at least 83%, 77% and 84% of all the hourly discharge data of Mima, Nara and Hiromi rivers, respectively, are below the mean value (*refer to* **Table 3.14**); hence, more classes are constructed below the mean discharge. Using aggregate data, there are 22, 18 and 21 data classes for Mima, Nara and Hiromi rivers, respectively. The four seasons (spring, summer, fall and winter) have 16, 17, 14 and 17 classes for Mima river; 18, 14, 11, 15 classes for Nara river; and 18, 14, 14, 13 classes for Hiromi river. The discharge data classes for both aggregate and seasonal data is presented in **Table 3.5**.Increasing the number of classes will not further improve the resulting regression equation, as well as its efficiency.

Notwithstanding its primary purpose of including the nil sediment values during regression analysis, the data stratification procedure improves the factors (Q-SD) correlation (**Fig. 3.15**) and model efficiency coefficient, thereby making the derived prediction models more capable of estimating the sediment load. Similar procedure has been employed by previous suspended sediment estimation and studies (Verhoff *et al.*, 1980; Jansson, 1996). Walling and Webb (1981) showed that when using mean loads in water discharge classes the order of magnitude of the load was correct.

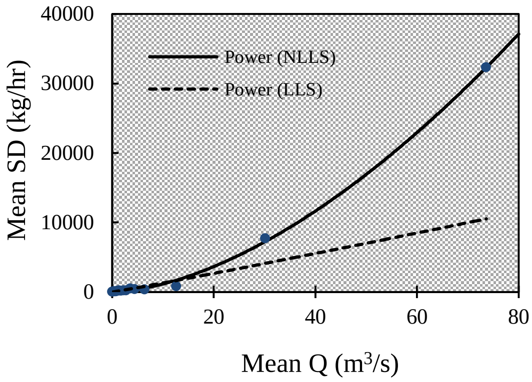
### 3.4.2.3 Regression analysis and sediment curves

The suspended sediment load was estimated by regression analysis using river discharge-suspended sediment discharge correlation in the form, $SD=aQ^b$. Regression equations for the aggregate and seasonally clustered data were derived without logarithmic transformation as Q values are only up to 2 degrees of magnitude, unlike previous studies involving relatively large rivers (Jansson, 1992; Sadeghi *et al.*, 2008; Hu *et al.*, 2011; Gao and Josefson, 2012) where log transformation is necessary to standardized the errors due to large range of suspended sediment values.

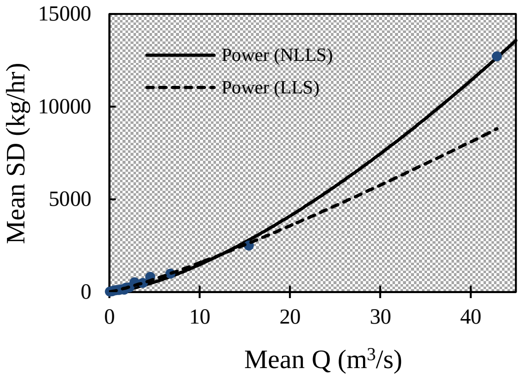
The suspended sediment rating curves derived as a power function using linear least squares (LLS) and non-linear least squares (NLLS) methods are presented in **Figs. 3.16** to **3.18** NLLS method was proposed by some investigators (Jansson, 1985a; Bates and Watts, 1988) to estimate the parameters of the suspended sediment rating curve to avoid the transformation bias problem in LLS method. The fundamental difference between the two methods is in the residual term: multiplicative in LLS but additive in NLLS. According to Crawford (1991) the residual errors of the non-linear model typically are highly skewed and are not identically distributed, but the problem could be addressed by log-transformation. Nevertheless, for the rivers studied, the curves developed using NLLS



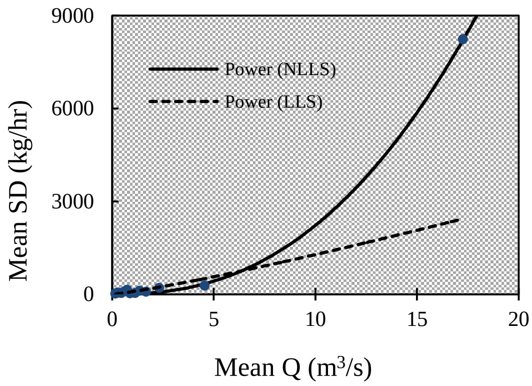

a. Aggregate Data



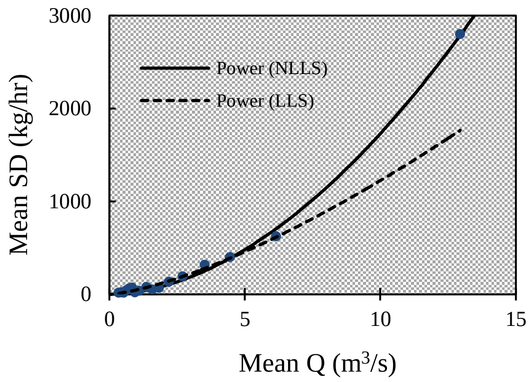

b. Spring




c. Summer




d. Fall




e. Winter

Figure 3.16: Mima river's suspended sediment rating curves using LLS and NLLS regression methods

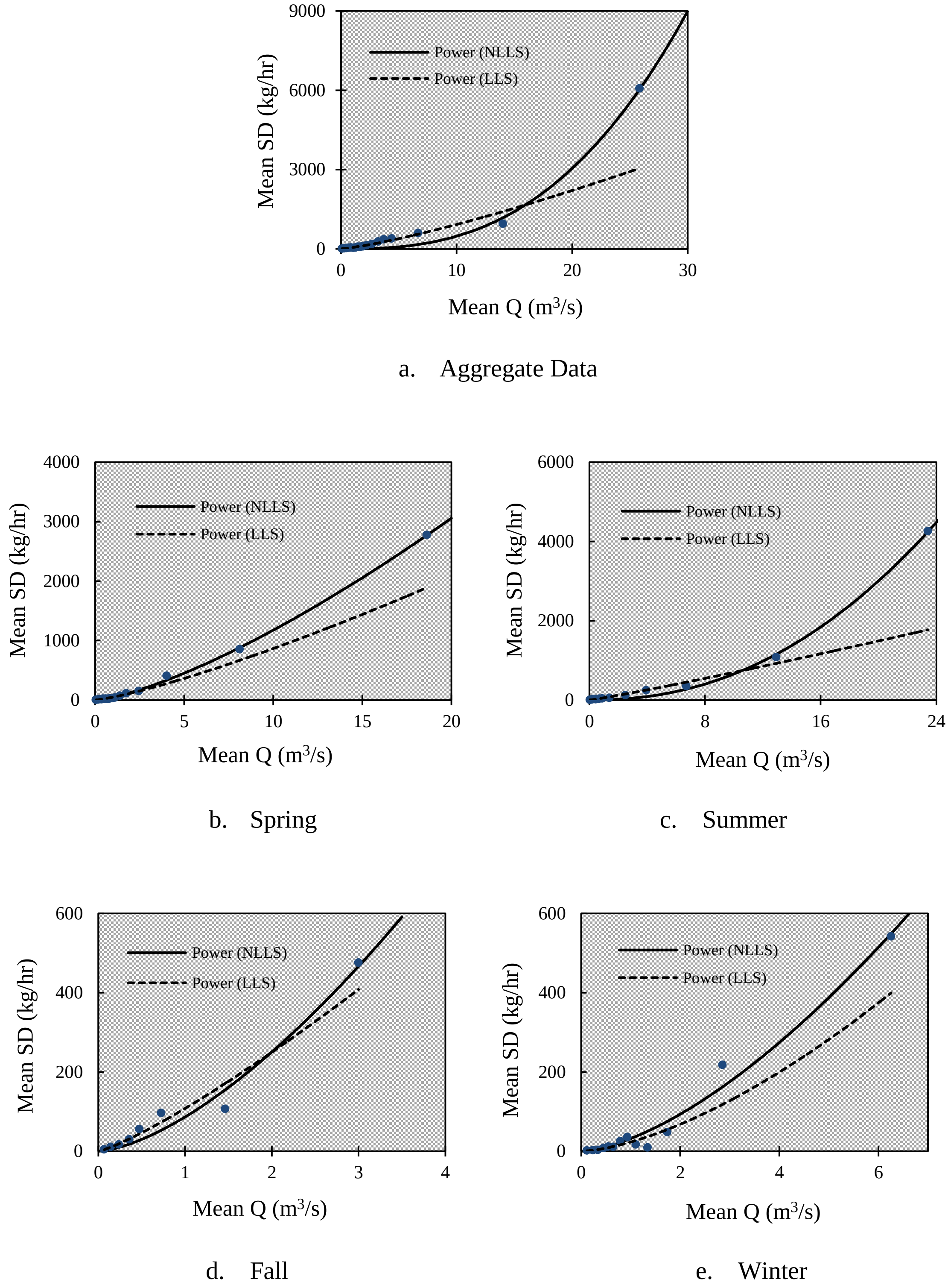
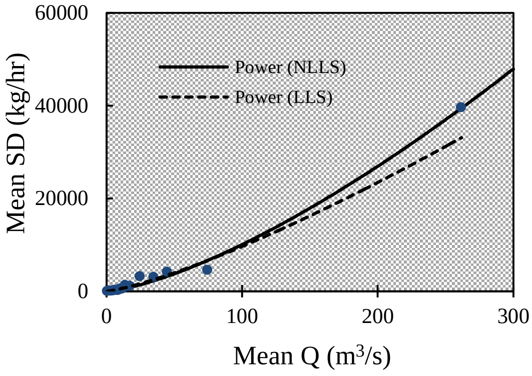
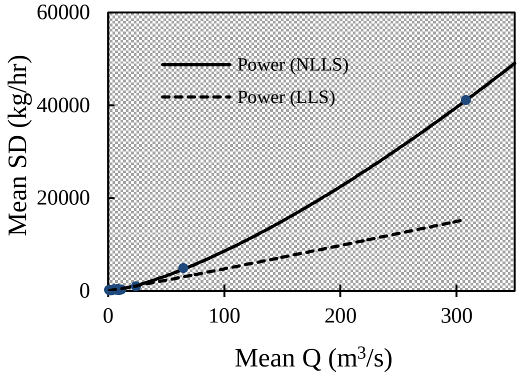


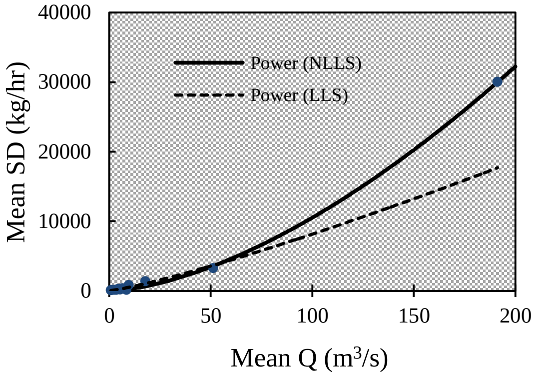

Figure 3.17: Nara river's suspended sediment rating curves using LLS and NLLS regression methods



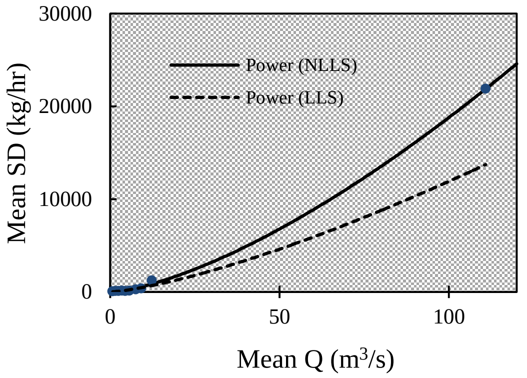

a. Aggregate Data



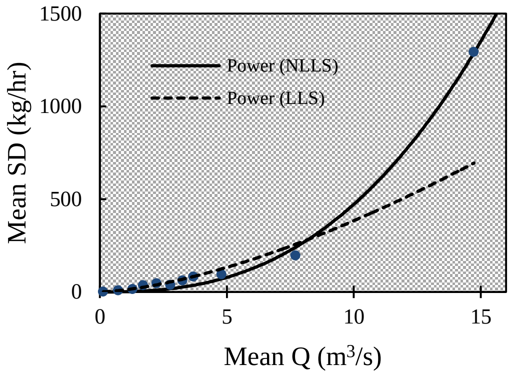

b. Spring




c. Summer




d. Fall




e. Winter

Figure 3.18: Hiromi river's suspended sediment rating curves using LLS and NLLS regression methods

Table 3.6: Mima river's suspended sediment load equations ($SD$=a$Q^b$), correlation coefficient ($R^2$) and model efficiency coefficients [$e_f$]

| Data | LLS | NLLS |
|---|---|---|
| Aggregate | $SD = 91.3Q^{1.135}$ (0.994) [***0.532***] | $SD = 40.1Q^{1.512}$ (0.996) [***0.864***] |
| Spring | $SD = 114.3Q^{1.052}$ (0.927) [***0.423***] | $SD = 24.3Q^{1.673}$ (0.999) [***0.915***] |
| Summer | $SD = 103.64Q^{1.182}$ (0.970) [***0.836***] | $SD = 49.4Q^{1.475}$ (0.998) [***0.871***] |
| Fall | $SD = 85.2Q^{1.177}$ (0.782) [***0.499***] | $SD = 8.9Q^{2.393}$ (0.999) [***0.832***] |
| Winter | $SD = 46.9Q^{1.416}$ (0.907) [***0.741***] | $SD = 24.5Q^{1.848}$ (0.998) [***0.850***] |

Table 3.7: Nara river's suspended sediment load equations ($SD$=a$Q^b$), correlation coefficient ($R^2$) and model efficiency coefficients [$e_f$]

| Data | LLS | NLLS |
|---|---|---|
| Aggregate | $SD = 52.4Q^{1.236}$ (0.960) [***0.529***] | $SD = 1.01Q^{2.674}$ (0.989) [***0.843***] |
| Spring | $SD = 48.3Q^{1.253}$ (0.964) [***0.637***] | $SD = 49.0Q^{1.380}$ (0.999) [***0.666***] |
| Summer | $SD = 56.1Q^{1.095}$ (0.958) [***0.375***] | $SD = 4.22Q^{2.192}$ (0.998) [***0.831***] |
| Fall | $SD = 107.9Q^{1.211}$ (0.975) [***0.618***] | $SD = 86.4Q^{1.535}$ (0.973) [***0.653***] |
| Winter | $SD = 23.2Q^{1.552}$ (0.901) [***0.525***] | $SD = 31.9Q^{1.553}$ (0.979) [***0.595***] |

Table 3.8: Hiromi river's suspended sediment load equations ($SD$=a$Q^b$), correlation coefficient ($R^2$) and model efficiency coefficients [$e_f$]

| Data | LLS | NLLS |
|---|---|---|
| Aggregate | $SD = 28.7Q^{1.261}$ (0.951) [***0.687***] | $SD = 14.5Q^{1.420}$ (0.994) [***0.785***] |
| Spring | $SD = 38.2Q^{1.047}$ (0.830) [***0.356***] | $SD = 13.8Q^{1.395}$ (0.999) [***0.877***] |
| Summer | $SD = 33.5Q^{1.193}$ (0.910) [***0.422***] | $SD = 6.15Q^{1.616}$ (0.999) [***0.722***] |
| Fall | $SD = 21.7Q^{1.370}$ (0.926) [***0.676***] | $SD = 21.4Q^{1.472}$ (0.999) [***0.667***] |
| Winter | $SD = 11.2Q^{1.535}$ (0.976) [***0.585***] | $SD = 1.21Q^{2.592}$ (0.996) [***0.770***] |

Table 3.9 Wilcoxon-Mann-Whitney test *p-values* on correlation coefficient ($R^2$) and model efficiency coefficients [$e_f$]

| Parameter/Statistic | River | | | |
|---|---|---|---|---|
| | Mima | Nara | Hiromi | All |
| LLS-NLLS: $R^2$ | 0.012 | 0.016 | 0.063 | <0.0001 |
| $e_f$ | 0.016 | 0.032 | 0.032 | <0.0001 |
| Aggregate-Seasonal: $R^2$ | 0.967 | 0.980 | 0.700 | 0.975 |
| $e_f$ | 0.980 | 0.259 | 0.096 | 0.327 |

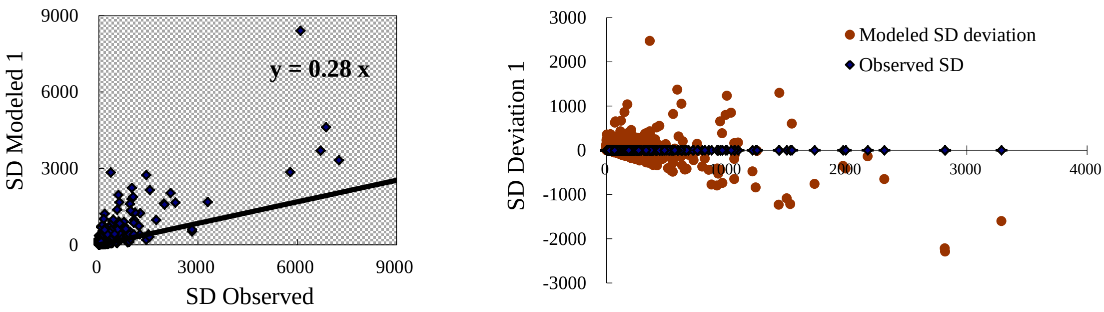
method, though not log-transformed, have a better fit than those developed by LLS method, with higher correlation and model efficiency coefficients (**Tables 3.6** to **3.8**).

As evident in the figures, the curves developed through LLS method tended to be biased to the smaller values; hence, high values especially during storm events are not well-presented in the curve. These results to highly underestimate sediment load values. A usual correction method applied is to construct separate suspended sediment rating curves for low and high values (Jansson, 1996; Gao and Josefson, 2012) which may not anymore be necessary when applying regression analysis using NLLS method. In fact, using NLLS method, an almost perfect correlation and high efficiency coefficients could be attained when applied to mean values within discharge classes (data stratification) (**Table 3.9**).

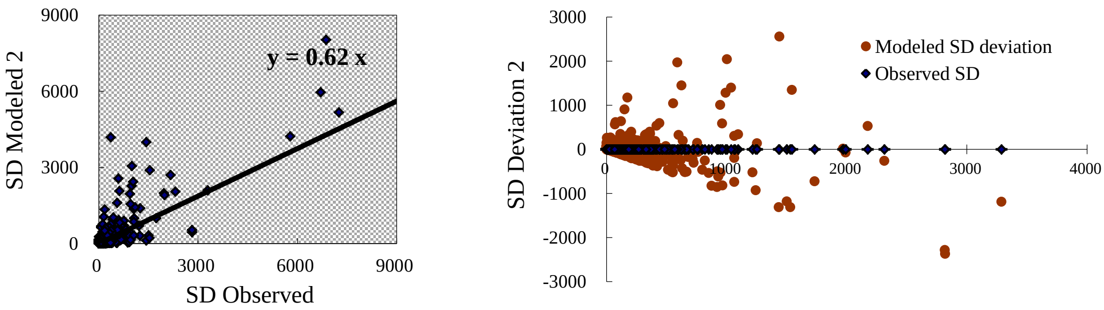
The resulting regression equations are applied to all daily discharge values to determine its correlation and efficiency. Analysis revealed that NLLS method produced rating curves that have high factor correlation or coefficient of determination ($R^2$) and could estimate suspended sediment loads with highly significant accuracy, whether using aggregate or seasonally clustered data (**Table 3.9**).

As to coefficient of determination ($R^2$), the ratings curves by NLLS has just slightly higher values than rating curves by LLS and is apparently insignificant: 0.2%, 3% and 5% higher for Mima, Nara and Hiromi rivers, respectively, using aggregated data or 8%~28%, -0.2%~9% and 2%~20% higher using seasonal data, respectively. In fact, during fall season in Nara river, LLS has a slightly higher $R^2$ value than NLLS, at 0.2%. Comparing the $R^2$ value of aggregate and seasonally-clustered data, the value is higher when using NLLS but most often lower when using LLS, although but difference is also insignificant.

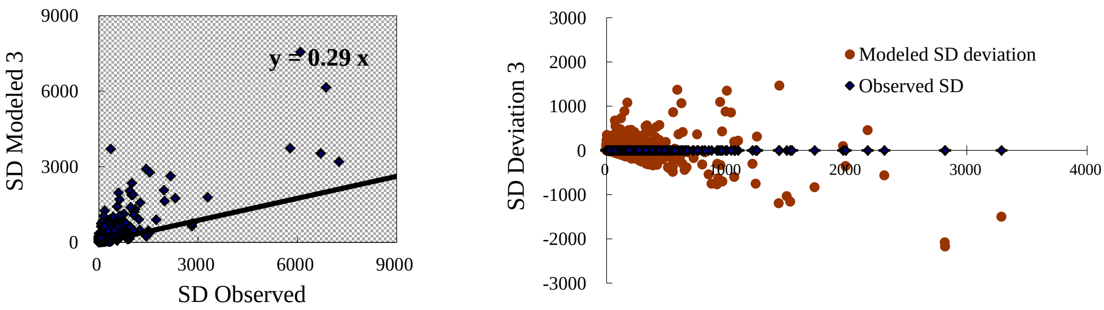
Rating curves developed using NLLS proved to be better in prediction or estimation of sediment values as it generally has significantly higher model coefficient values ($e_f$) than rating curves developed using LLS: 62%, 58% and 14% higher using aggregated data of Mima, Nara and Hiromi rivers, respectively. For seasonally-clustered data, some seasons have higher $e_f$ than aggregated data, although some have lower values. In Mima river, seasonally-clustered data has $e_f$ of 4%~116% or an average of 51%; 5%~122% or an average



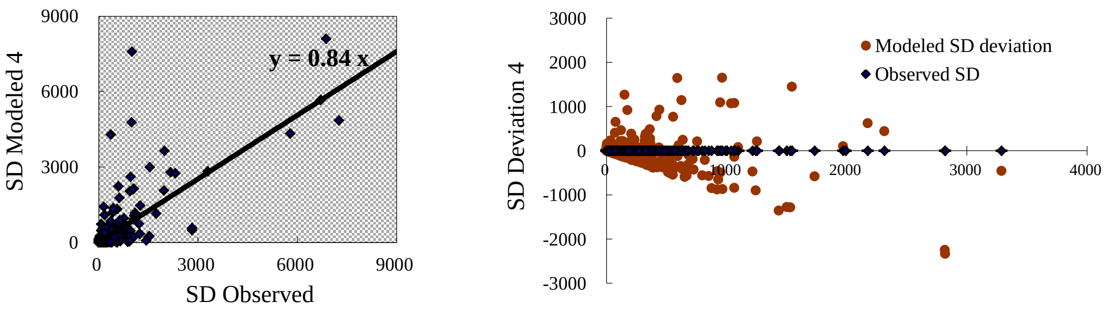

1. Aggregated data by LLS




2. Aggregated data by NLLS

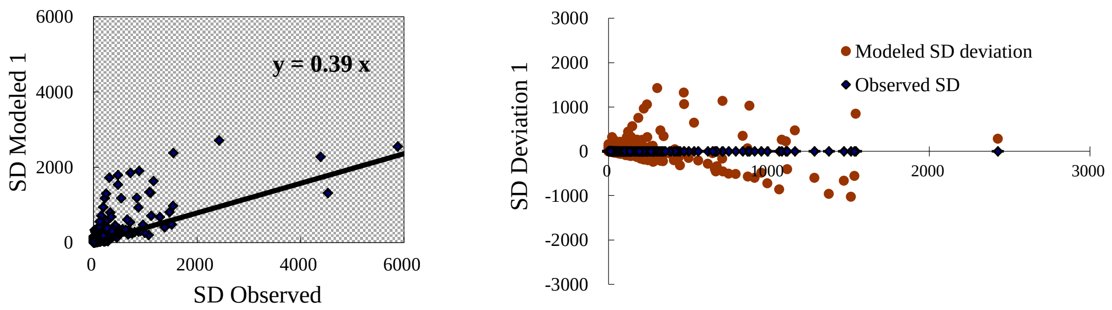



3. Seasonally-clustered data by LLS

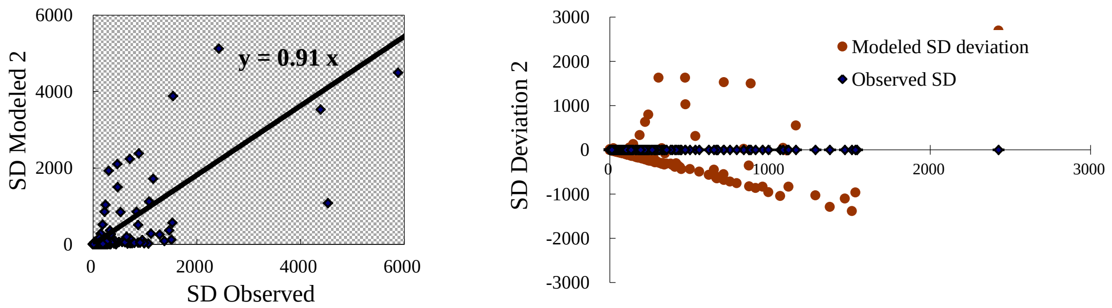



4. Seasonally-clustered data by NLLS

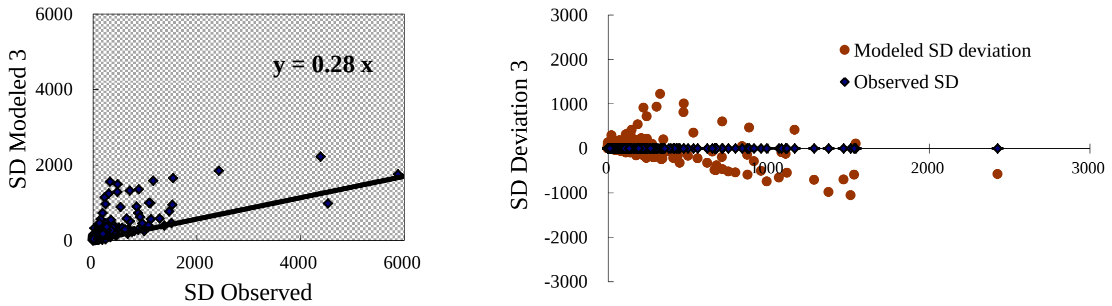
Figure 3.19: Mima river observed SD and modeled SD values correlation and scatter plots of SD deviation



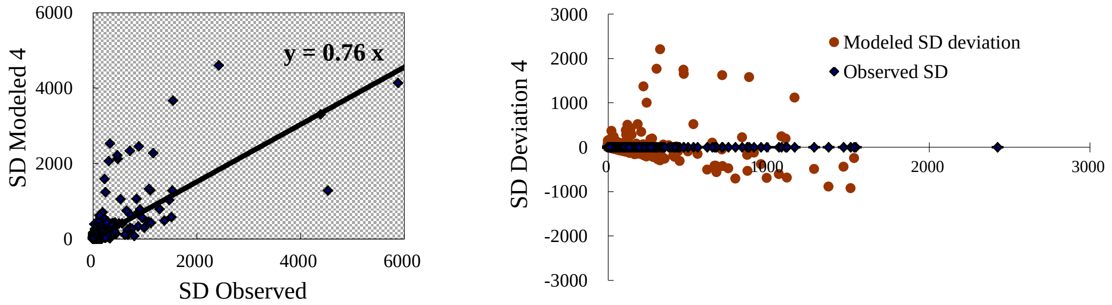

1. Aggregated data by LLS




2. Aggregated data by NLLS

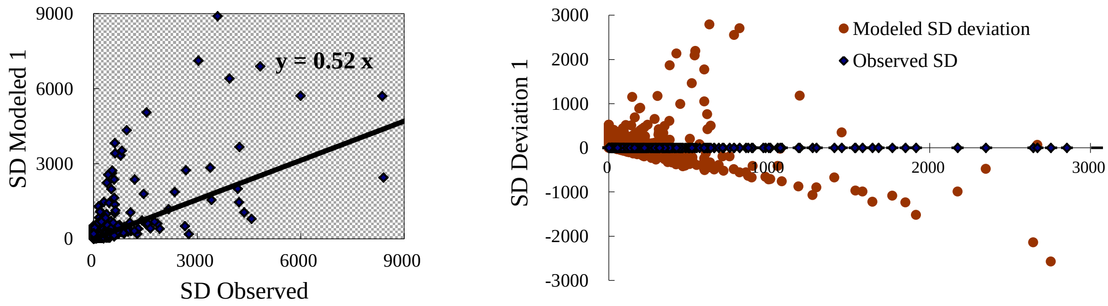



3. Seasonally-clustered data by LLS

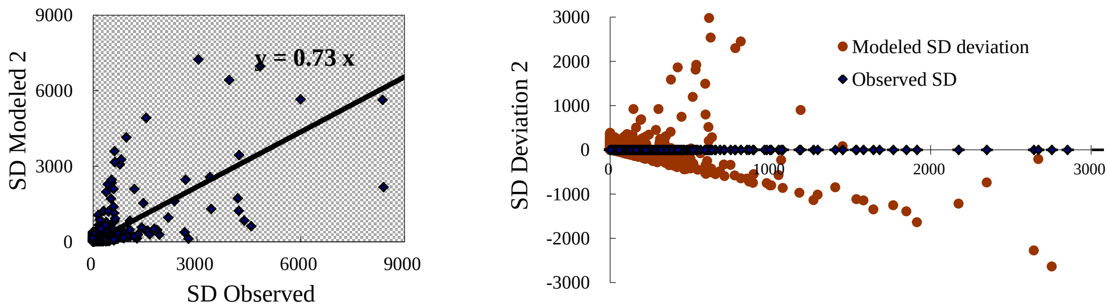



4. Seasonally-clustered data by NLLS

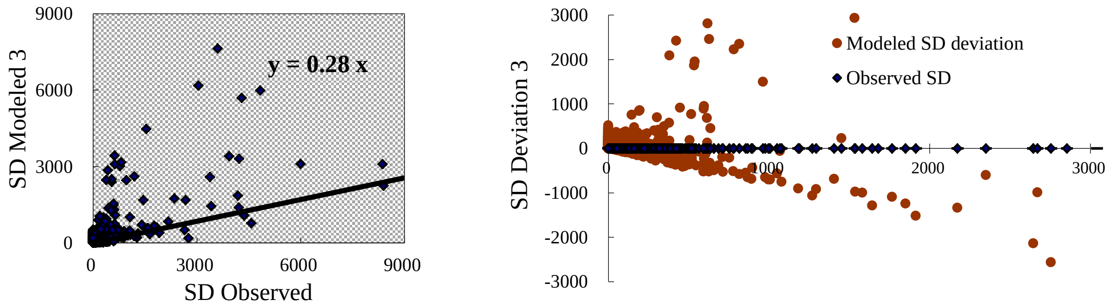
Figure 3.20: Nara river observed SD and modeled SD values correlation and scatter plots of SD deviation



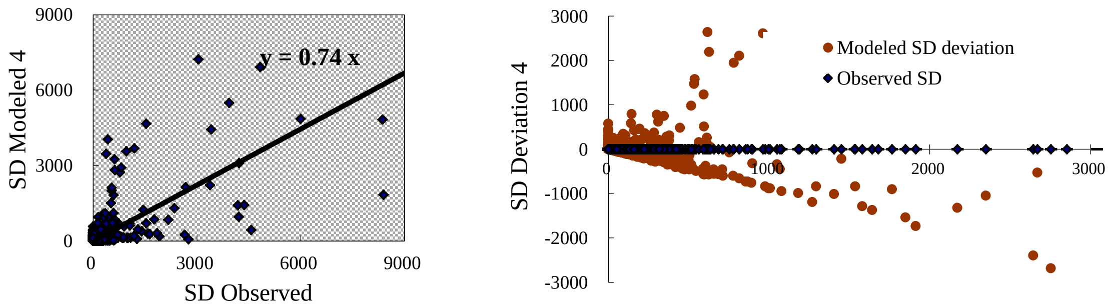

1. Aggregated data by LLS




2. Aggregated data by NLLS




3. Seasonally-clustered data by LLS




4. Seasonally-clustered data by NLLS

Figure 3.21: Hiromi river observed SD and modeled SD values correlation and scatter plots of SD deviation

of 37% in Nara river; and -1%~143% or an average of 61% in Hiromi river. Combining the data of the four seasons together, the $e_f$ is 0.519, 0.402 and 0.430 for LLS in Mima, Nara and Hiromi rivers, respectively, and 0.869, 0.801 and 0.803 for the NLLS of the rivers, respectively. Hence, it can be inferred from the analysis that NLLS method is better than LLS method for both aggregated and seasonal data.

The test on significant difference using the non-parametric Wilcoxon-Mann-Whitney test showed that, indeed, NLLS method is significantly different from LLS method—significantly better—with significantly higher $R^2$ and $e_f$ at 5% confidence interval (p=0.05) using each river's data separately and at 1% confidence interval (p=0.001) using data of all rivers simultaneously (**Table 3.9**). On the other hand, aggregated and seasonally-clustered data is statistically not significantly different, based on the Wilcoxon-Mann-Whitney test, except for the $e_f$ in Hiromi river which is significantly different between aggregated and seasonally-clustered data at 10% confidence interval (p=0.10). The rest are not significantly different—having a very high probability values, some of which are close to unity (p=1 means absolutely not significantly different).

The correlation of observed SD and modeled SD values supplements and attests the earlier inferences and analysis results. All observed-modeled SD correlation coefficients showed that ratings curves or prediction models established by NLLS methods has significantly better prediction or estimation capability than those established by LLS method, as indicated by much higher values: 121% and 190% higher in Mima river, 133% and 171% higher in Nara river, and 40% and 164% higher in Hiromi river or an average of 156%, 152% and 102% for the three rivers, respectively (*refer to* **Fig. 3.19** to **21**). Moreover, correlation coefficient values are higher only for seasonally-clustered data in Mima river while lower in both Nara and Hiromi rivers, ascertaining the earlier finding that seasonally-clustering the data does not necessarily results to a better rating curves or prediction model equations.

#### 3.4.2.4 Modeled sediment load

The established sediment rating curves or regression model equations are applied to all daily discharge values to determine its efficiency for suspended sediment load estimation. The estimated annual suspended sediment load values presented in **Tables 3.10** to **3.12** showed underestimated values, except in Hiromi river where both aggregate and seasonal data are overestimated by NLLS method. However, whether underestimated or overestimated, the estimated annual SL is obviously closer to the actual or observed load.

In Mima river, estimated annual SL using aggregate data is 35% and 19% lower than the actual load, by LLS and NLLS methods, respectively. In Nara river, it is 11% and 3% lower, respectively; while 0.4% lower and 9% higher in Hiromi river. For seasonal data, it is 26% and 15% lower in Mima river, 20% and 0.5% in Nara river, while 4% lower and 9% higher in

Table 3.10: Mima river observed and estimated annual and seasonal sediment load ($\times 10^3$ kg)

| Data/Season | Actual/ Observed | Regression Method | |
|---|---|---|---|
| | | LLS | NLLS |
| Aggregate | 3264 | 2119 | 2657 |
| Seasonal | 3264 | 2396 | 2775 |
| Spring | 954 | 710 | 863 |
| Summer | 1320 | 1097 | 1238 |
| Fall | 804 | 145 | 515 |
| Winter | 186 | 174 | 159 |

Table 3.11: Nara river observed and estimated annual and seasonal sediment load ($\times 10^3$ kg)

| Data/Season | Actual/ Observed | Regression Method | |
|---|---|---|---|
| | | LLS | NLLS |
| Aggregate | 811 | 721 | 786 |
| Seasonal | 811 | 648 | 807 |
| Spring | 239 | 166 | 241 |
| Summer | 388 | 283 | 343 |
| Fall | 131 | 156 | 162 |
| Winter | 53 | 44 | 60 |

Table 3.12: Hiromi river observed and estimated annual and seasonal sediment load ($\times 10^3$ kg)

| Data/Season | Actual/ Observed | Regression Method | |
|---|---|---|---|
| | | LLS | NLLS |
| Aggregate | 7127 | 7102 | 7801 |
| Seasonal | 7127 | 6837 | 7740 |
| Spring | 1693 | 2702 | 2176 |
| Summer | 4649 | 2926 | 3814 |
| Fall | 628 | 1078 | 1650 |
| Winter | 157 | 131 | 99 |

Table 3.13: Wilcoxon-Mann-Whitney test *p-values* on annual sediment load (SL)

| Parameter/Statistic | River | | | |
|---|---|---|---|---|
| | Mima | Nara | Hiromi | All |
| LLS-NLLS | 0.631 | 0.739 | 0.912 | 0.807 |
| Aggregate-Seasonal | 0.780 | 0.999 | 0.400 | 0.999 |
| Actual-Aggregate | 0.412 | 0.940 | 0.960 | 0.853[a] |
| Actual Seasonal | 0.385 | 0.718 | 0.945 | 0.796 [b] |

[a] *LLS=0.756, NLLS=0.967* [b] *LLS=0.796, NLLS=0.870*

Hiromi river, using LLS and NLLS methods, respectively. Hence, it could be inferred that NLLS method would give a better estimates than LLS method, although it has a tendency to overestimate the annual SL.

Among the seasons, spring and fall showed overestimated values: 0.8% (NLLS) during spring and 19% (LLS) and 24% (NLLS) during fall in Nara river, and 60% (LLS) and 29% (NLLS) during spring and 72% (LLS) and 163% (NLLS) during fall in Hiromi river. The overestimation, as well as underestimation, of annual SL could be attributed to the supposedly outlier values during low flow but with high SC values and the few but high SC values during extremely high flow or flood events which could have affected the factor correlation and model efficiency. Low flow but high SC values characterizes most flow during spring, as affected by agricultural drainage and effluents; while high flow with high SC values characterizes fall season which coincides with the high rainfall and typhoon season that brings about high occurrence of natural soil erosion.

Seasonally-clustered data generally results to higher and better SL estimates which are closer to the actual or observed SL, particularly when using NLLS method. NLLS method showed a closer SL estimates between aggregate and seasonally-clustered data, with only 4%, 3% and 1% difference in Mima, Nara and Hiromi river, respectively; compared to the 13%, 10% and 4% difference when using LLS method. Moreover, LLS method tends to give lower estimates when using seasonally-clustered data, as in the case of Nara and Hiromi rivers (**Tables 3.10** to **3.12**).

The statistical test on significant difference among SL values, using the non-parametric Wilconxon-Mann-Whitney test, showed that SL estimates by LLS and methods are statistically not significantly different (**Table 3.13**). SL estimates using aggregated or seasonally-clustered data are also not significantly different, especially in Nara river (p=0.999) and considering the data of all rivers (p=0.999). Further, both aggregated and seasonally-clustered data are not significantly different from the actual or observed SL. However, considering LLS or NLLS methods, the latter gives a closer estimated SL value to the actual SL value (*see footnote of* **Table 3.13**). Thus, it could be opined that under any type of data, NLLS tend to give a better annual SL estimates.

### 3.4.3 Water Duration Analysis

The water duration analysis was conducted to better understand the sediment transport in the rivers by determining the "effective water discharge" or the discharge which transports most (the significant part) of the sediment load. It is determined by plotting the discharge classes with equal range against the water days (water duration) and sediment discharge. Then, the sediment load is calculated using the mean of each discharge class.

In this study, the focus of water duration analysis are the low flows which is apparently affected by the sediment coming from agricultural areas though drainage and effluents, particularly those from rice paddy fields. The delineation of the 'low flow' to be considered in further analysis was based on the discharge and sediment load data composition, which reflects the amount of data (in percentage) of a particular range of Q out of the total hourly data monitored using a data logger. Within the 4-year monitoring period, there a total of 32,229 hourly Q data for Mima river, 27,887 for Nara river, and 30,826 for Hiromi river. The difference is accounted to some data logger breakdown and missing data.

Table 3.14: Water-hour and sediment load transport data composition

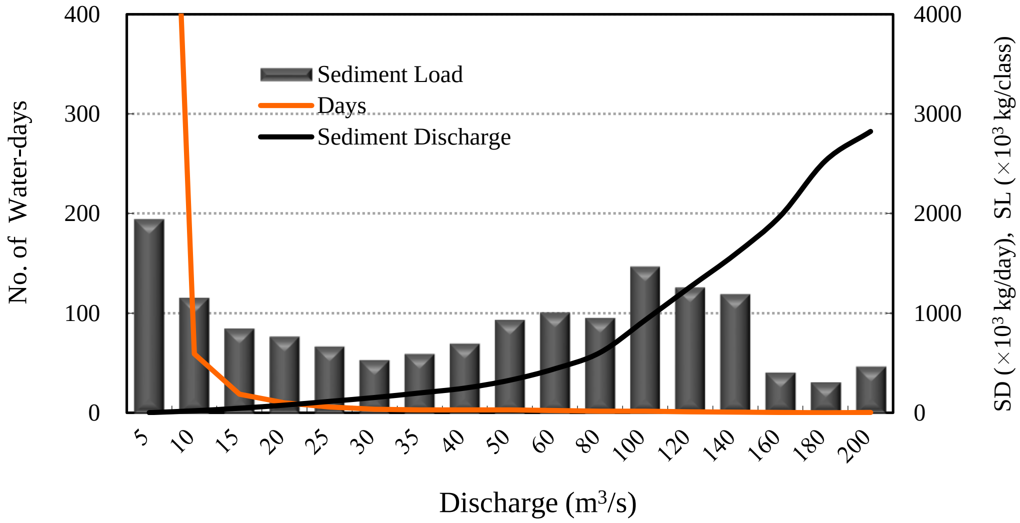
| Discharge | Mima River | | Nara River | | Hiromi River | |
|---|---|---|---|---|---|---|
| | % Water Hour | % SL ($Q \leq 10\ m^3/s$) | % Water Days | % SL ($Q \leq 10\ m^3/s$) | % Water Days | % SL ($Q \leq 20\ m^3/s$) |
| Mean Q* | 83 | 39 | 77 | 5 | 84 | 49 |
| 5 $m^3/s$ | 92 | 63 | 95 | 34 | - | - |
| 10 $m^3/s$ | 96 | 100 | 98 | 100 | 92 | 71 |
| 20 $m^3/s$ | 98 | - | 99 | - | 98 | 100 |

*Mean Q: Mima=2.74 $m^3/s$, Nara=1.22 $m^3/s$, Hiromi=7.40 $m^3/s$

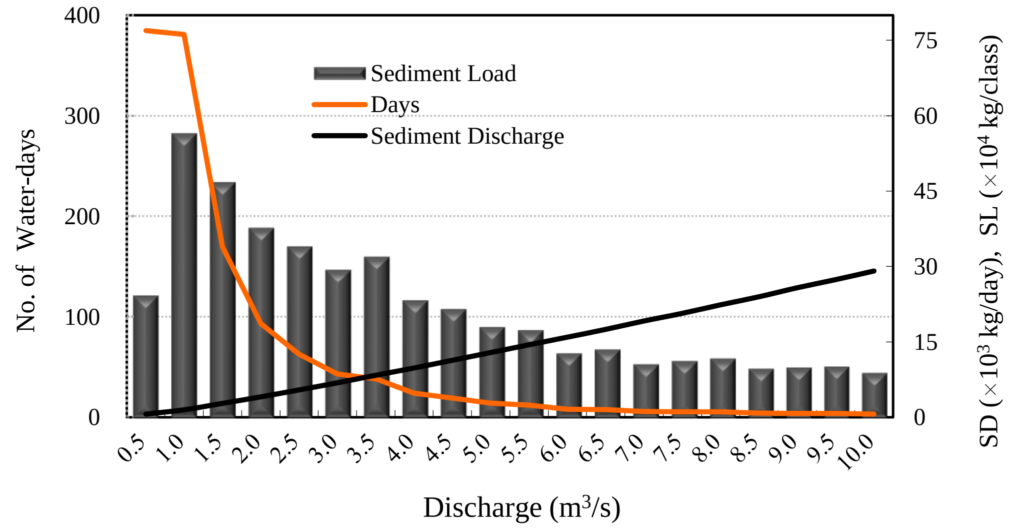
The water-hour and SL transport data composition in **Table 3.14** shows that hourly Q data below the average or mean Q consist a significant portion of the Q data: 83%, 77% and 84% in Mima, Nara and Hiromi rivers, respectively. At 10 $m^3/s$, the Q data of Mima and Nara rivers comprised 96% and 98%, respectively, while 92% in Hiromi river.

In order to make a rather conclusive analysis for lower flow, hourly data comprising at least 95% of the total data was used, making it somewhat comparable to a 95% confidence interval. Hence, the limiting Q for Mima and Nara rivers is 10 $m^3/s$ and 20 $m^3/s$ for Hiromi river. Moreover, the water duration analysis is also done using all monitored or available Q data.

Considering $Q \leq 10\ m^3/s$, discharge below the mean Q transports approximately 39% and 15% of the SL in Mima and Nara rivers, respectively. Considering $Q \leq 10\ m^3/s$ for Hiromi

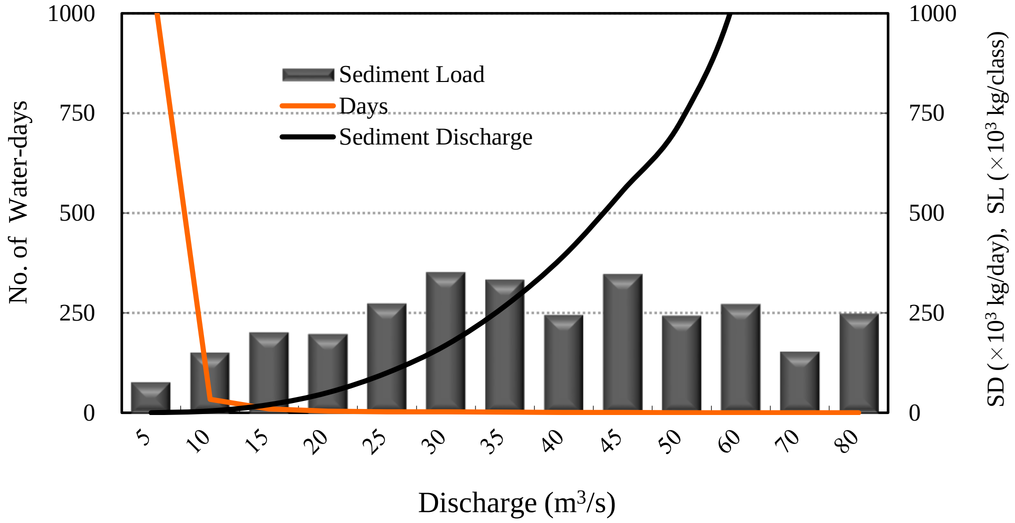



a. All Q data

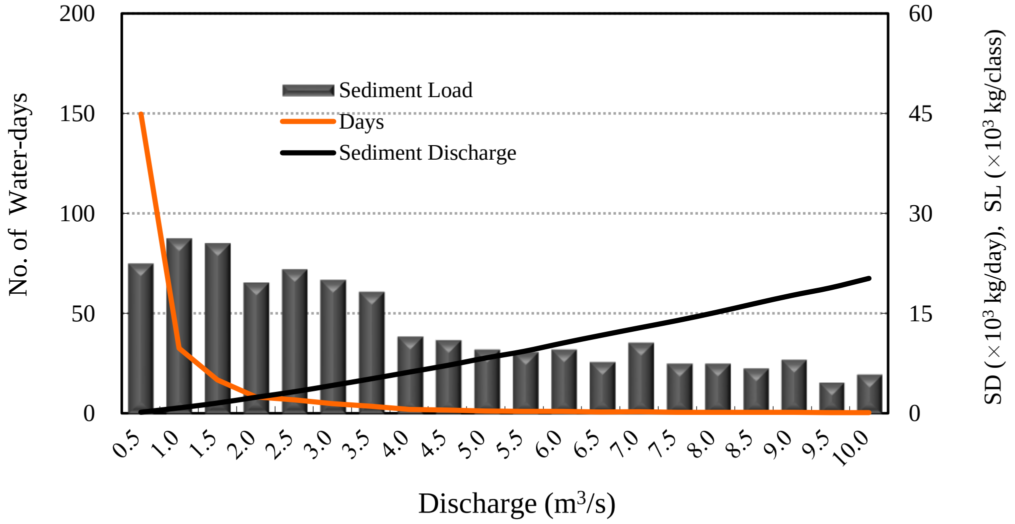



b. $Q \leq 10$ m$^3$/s

Figure 3.22: Mima river water duration curves and sediment load using sediment rating curve of aggregated data by NLLS

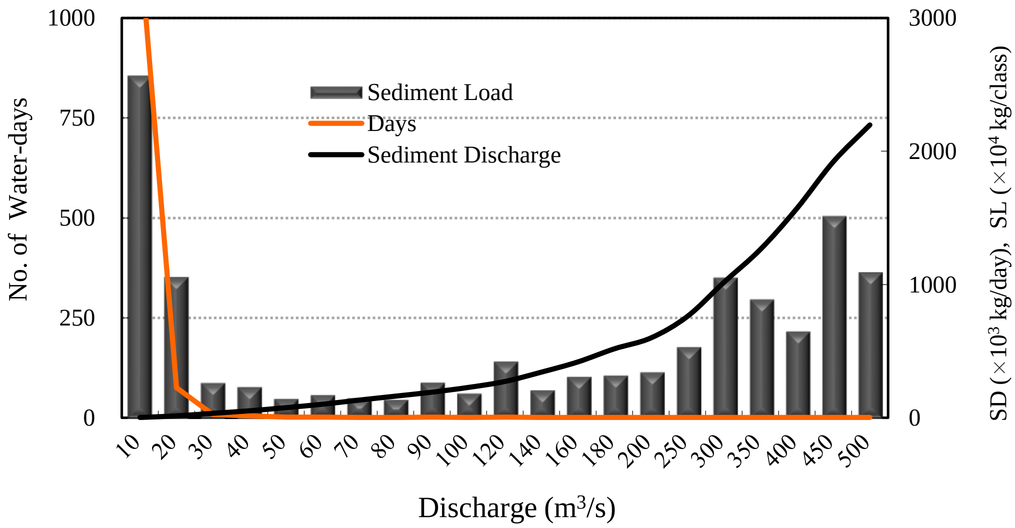



a. All Q data

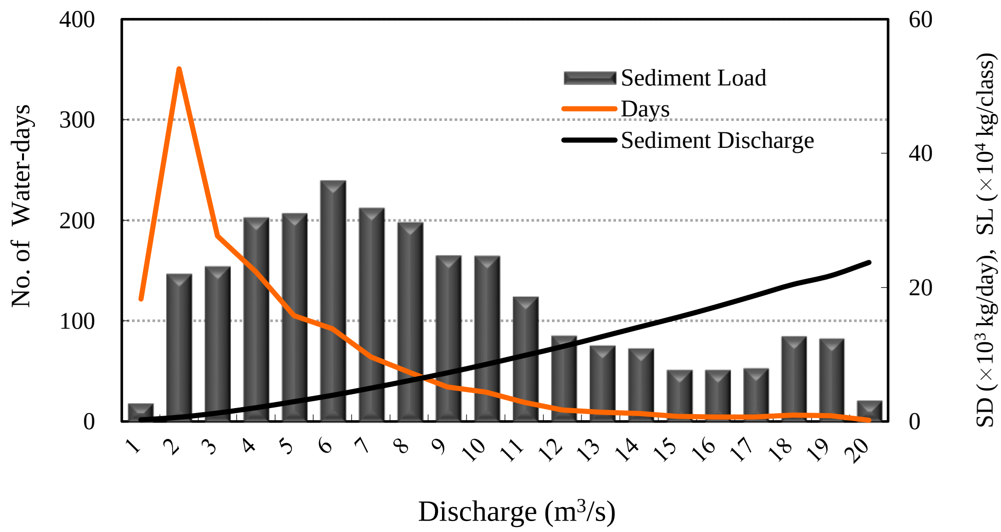



b. $Q \leq 10\ m^3/s$

Figure 3.23: Nara river water duration curves and sediment load using sediment rating curve of aggregated data by NLLS




c. All Q data




d. $Q \leq 20$ m$^3$/s

Figure 3.24: Hiromi river water duration curves and sediment load using sediment rating curve of aggregated data by NLLS

river, discharge below its mean Q transports 49% of the SL (**Table 3.14**). At half of the limiting Q (5 $m^3$/s for Mima and Nara rivers, 10 $m^3$/s for Hiromi), transported SL is at 63%, 34% and 71%, respectively. Thus, it can be inferred that a significant portion of the SL is transported at low Q. However, it might be insignificant when considering all discharge data as the very few but extremely high Q naturally transports the bulk of SL.

The water duration curves in **Figs. 3.22** to **3.24** shows that, considering a limiting Q, the transported sediment load generally decreases as Q increases. However, considering all Q data, there is also a rise of transported sediment load at very high Q values despite a very low equivalent number of water-days. This could be attributed to the very few high Q values with equivalent extremely high SC and SD resulting to a very high SL.

The ‘most effective’ discharge, as used in this study, would be the range of discharge that transports 90% of the sediment load, considering a limiting discharge defining low flows. Based on the data analysis, as reflected in **Figs. 3.21** to **3.23**, the most effective discharge is $Q \leq 8.5$ $m^3$/s, $Q \leq 9.0$ $m^3$/s and $Q \leq 16$ $m^3$/s for Mima, Nara and Hiromi rivers, respectively.

### 3.4.4 Impact of Rice Transplanting Activities

The impact of rice transplanting activities in the sediment load of the river was determined by computing the sediment load during rice transplanting season that falls on the months of April to June in Mima river watershed and on April to May in Nara and Hiromi rivers.

The analysis and quantification of the impact or contribution of rice transplanting activities in the rivers’ SL commences with seasonally-clustering the data into rice (RTS) and non-rice transplanting season (NRTS). Sediment rating curves are established by LLS and NLLS regression method and applying data stratification (*refer procedure to* **Sections 3.4.2.2** and **3.4.2.3**). The number of data sets (Q-SD) for RTS is 253, 219 and 141 for Mima, Nara and Hiromi rivers, respectively, while 719, 751 and 804, respectively, for NRTS. By the data stratification, the number of Q classes for RTS is 15,13 and 16 for Mima, Nara and Hiromi rivers, respectively, and 18, 17 and 20 for NRTS.

The effect of rice transplanting activities as represented by SL contribution during the rice transplanting period was computed was computed, as shown in **Fig. 3.25**. The RTS ($SD_1$) and NRTS ($SD_2$) equations were applied on the discharge data during the rice transplanting period and the difference of the computed sediment load represents the effect.

The suspended sediment load apparently attributed to the activities during rice transplanting season, considering limiting Q, are approximately $175\times10^3$ kg, $12\times10^3$ kg, and $56\times10^3$ kg in Mima, Nara and Hiromi rivers, respectively. This translates into 43%, 23% and 17% contribution to the suspended sediment load transport during the rice transplanting period and approximately 5%, 1.5% and 0.8% of the total annual estimated load (**Table 3.15**). A suspended sediment sampling *in situ* (from rice paddy fields) yield an average of $5.4\times10^3$

kg/km$^2$, or an equivalent of $6.5\times10^4$ kg for the entire basin—approximately 59% of the estimated value.

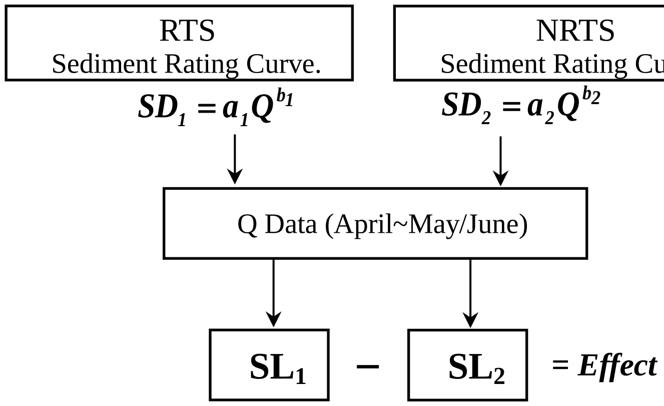



Figure 3.25: Process diagram in solving the effect of rice transplanting

Table 3.15: Estimated suspended sediment load during rice transplanting period ($\times10^3$ kg)

| **Equation** | **River** | | |
|---|---|---|---|
| | **Mima** *($Q \leq 10m^3/s$)* | **Nara** *($Q \leq 10m^3/s$)* | **Hiromi** *($Q \leq 20m^3/s$)* |
| RTS | 403 | 52 | 332 |
| NRTS | 228 | 40 | 276 |
| % Difference | 43% | 23% | 17% |
| Difference as % of Annual SL | 5% | 1.5% | 0.8% |

Among the rivers, Mima river receives the biggest amount of suspended sediment from the agricultural areas (43%) while Hiromi river the least (17%). This is indicative of the rivers' agricultural area, particularly rice paddy area, since Mima has the biggest area while Hiromi the smallest (*refer to* **Table 3.1**)

## 3.5 Summary

Suspended load in small agricultural catchments was conducted, elucidating the discharge-suspended sediment load characteristics, establishing rating curves and analyzing the suspended sediment load temporal variation. The rivers are considered small rivers, based on the international river classification. Mima, Nara and Hiromi rivers have catchment area of 73 km$^2$, 34 km$^2$ and 190 km$^2$, respectively, and with considerable portion of its arable area apportioned to rice paddy—88%, 60% and 70%, respectively.

The rivers' discharge and sediment data was first analyzed for its temporal variation and trend. The monthly temporal trend of SC and SD shows inconsistencies with respect to Q, particularly in some months within the March-September period. Moreover, monthly variation of SC shows multi-modal distribution with June, July and September having high SC values. The SC seasonal variation shows the same trend in the three rivers which is relatively high on spring, slightly lower on summer, highest on fall and decreases on winter.

The SC has a wide range of values—with a very high dispersion (CV=357~1036), skewness (Sk=17.1~18.4), and kurtosis (K=338~397)—showing the compounded effect of Q and inconsistent SC. The range is extremely high during Spring (due to onset of agricultural activities, *i.e.* land preparation) and during Fall (due to high storm events) while it is very low during Winter. Similar to SC values, SD values has some extremely high values while most values are low, as indicated by median and mean values that are much closer to the minimum value. But, while SD appears to be indicative of the size of river watershed area, SC is not as Hiromi river appears to have lower SC values than Mima and Nara rivers although it is 3 times and 6 times as large as the two rivers, respectively. Further, nil values accounted approximately 5% of the monitored SC values. The occurrence is highest on Winter (20% of the seasonal data) which is a period of low flow, as well as no agricultural activities.

The observed annual total suspended sediment load is $3{,}264\times10^3$ kg in Mima river, $811\times10^3$ kg in Nara river, and $7{,}127\times10^3$ kg in Hiromi river. The suspended sediment load follows an erratic pattern when considered during the whole monitoring period. However, it is generally high during the April-July period and drastically low during November-January period. Considering the average monthly suspended sediment load values, the load started to increase on April, reaching its peak during May-July and decreases towards December.

The most sediment-laden month is July for Mima and Nara rivers and June for Hiromi river, accounting 28%, 26% and 33% of the annual total suspended sediment load with corresponding 40%, 15% and 24% of the water yield, respectively. Among the seasons, summer has the bulk of the annual sediment load with 40%, 40% and 49%, corresponding to a water yield of 40%, 46% and 60% for the three rivers, respectively. On the other hand, winter has only 6%, 7% and 3% of the annual sediment load. Moreover, spring has relatively higher sediment load than fall despite a proportionately smaller difference in water yield.

The temporal trend of sediment load shows spring and summer season taking the bulk of the transported sediment in the rivers, particularly during the periods March-July. Specifically, the sediment load increases towards summers and decreases towards winter. On the average, almost half of the annual sediment load (46%) is delivered during Summer and almost a third during spring (31%). This totals to 77%, leaving only less a quarter of the suspended sediment (22%) delivered during the other two succeeding seasons.

For the regression analysis, as the river is small and registers nil suspended sediment during some periods, data stratification was introduced to account for the nil values and to improve the regression and resulting sediment rating curves. Suspended sediment discharge (SD) was used as the dependent variable during regression as sediment correlation (SC) has a poor correlation with discharge (Q). The suspended sediment rating curve as a power equation model was developed using least (LLS) and non-linear least squares (NLLS) regression methods, applying it to the aggregated and seasonally clustered data.

Regression analysis revealed that NLLS method produced rating curves that have high factor correlation or coefficient of determination ($R^2$) and could estimate suspended sediment loads with highly significant accuracy, whether using aggregate or seasonally clustered data.

As to coefficient of determination ($R^2$), the ratings curves by NLLS has just slightly higher values than rating curves by LLS and is apparently insignificant, *i.e.* 0.2%, 3% and 5% higher for Mima, Nara and Hiromi rivers, respectively, using aggregated data; and 8%~28%, -0.2%~9% and 2%~20% higher using seasonal data, respectively. Rating curves developed using NLLS proved to be better in estimating sediment values as it generally has significantly higher model efficiency coefficient values ($e_f$) than rating curves developed using LLS, *i.e.* 62%, 58% and 14% higher using aggregated data of Mima, Nara and Hiromi rivers, respectively. Combining the data of the four seasons together, the $e_f$ is 0.519, 0.402 and 0.430 for LLS in Mima, Nara and Hiromi rivers, respectively, and 0.869, 0.801 and 0.803 for the NLLS of the rivers, respectively. Hence, it can be inferred from the analysis that NLLS method is better than LLS method for both aggregated and seasonal data.

The estimated annual suspended sediment load (SL) values showed underestimated values, except in Hiromi river where both aggregate and seasonal data are overestimated by NLLS method. However, whether underestimated or overestimated, the estimated annual SL is obviously closer to the actual or observed load. On the average, using aggregated data, estimated annual SL by LLS is 15% lower than the observed annual SL of the rivers; while 4% lower by NLLS. For seasonal data, it is 17% lower by LLS and 2% lower by NLLS. Hence, it could be inferred that NLLS method would give a better estimates than LLS method, although it has a tendency to overestimate the annual SL.

Seasonally-clustered data generally results to higher and better SL estimates which are closer to the actual or observed SL, particularly when using NLLS method. NLLS method showed a closer SL estimates between aggregate and seasonally-clustered data, with only 4%, 3% and 1% difference in Mima, Nara and Hiromi river, respectively, compared to the 13%, 10% and 4% difference when using LLS method. Moreover, LLS method tends to give lower estimates when using seasonally-clustered data, as in the case of Nara and Hiromi rivers.

The test on significant difference using the non-parametric Wilcoxon-Mann-Whitney test showed that, indeed, NLLS method is significantly different from LLS method—significantly better—with significantly higher $R^2$ and $e_f$ at 5% confidence interval (p=0.05) using each river's data separately and at 1% confidence interval (p=0.001) using data of all rivers. On the other hand, aggregated and seasonally-clustered data is statistically not significantly different. The significance test among SL values showed that SL estimates by LLS and methods are statistically not significantly different. SL estimates using aggregated or seasonally-clustered data are also not significantly different, especially in Nara river (p=0.999) and considering the data of all rivers (p=0.999). Further, both aggregated and seasonally-clustered data are not significantly different from the actual or observed SL. However, considering LLS or NLLS methods, the latter gives estimated SL values that are closer to the actual SL value.

The correlation of observed SD and modeled SD values showed that ratings curves or prediction models established by NLLS methods has significantly better prediction or estimation capability than those established by LLS method, as indicated by much higher correlation values, *i.e.* an average of 156%, 152% and 102% for Mima, Nara and Hiromi rivers, respectively. For seasonally-clustered data Correlation coefficient values are higher only in Mima river while lower in both Nara and Hiromi rivers, ascertaining the finding that seasonally-clustering the data does not necessarily results to a better rating curves or prediction model equations.

The water duration analysis, with the water-hour and SL transport data composition, shows that hourly discharge data below the average or mean Q already comprise a significant portion of the Q data, *i.e.* 83%, 77% and 84% in Mima, Nara and Hiromi rivers, respectively. From this, the limiting Q for further analysis was set: 10 $m^3/s$ for Mima and Nara rivers and 20 $m^3/s$ for Hiromi river. The water duration data and curves showed that, considering a limiting Q, the transported sediment load generally decreases as Q increases. However, considering all Q data, there is also a rise of transported sediment load at very high Q values despite a very low equivalent number of water-days which can could be attributed to the very few high Q values with equivalent extremely high SC and SD resulting to a very high SL. The ‘most effective’ discharge or the range of discharge that transports 90% of the sediment load, considering the limiting Q is $Q \leq 8.5$ $m^3/s$, $Q \leq 9.0$ $m^3/s$ and $Q \leq 16$ $m^3/s$ for Mima, Nara and Hiromi rivers, respectively.

The suspended sediment load apparently attributed to the activities during rice transplanting season are approximately $175\times10^3$ kg, $12\times10^3$ kg, and $56\times10^3$ kg in Mima, Nara and Hiromi rivers, respectively. This translates into 43%, 23% and 17% contribution to the suspended sediment load transport during the rice transplanting period and approximately 5%, 1.5% and 0.8% of the total annual estimated load. As inferred from this analysis results, Hiromi river was the least impacted by rice transplanting activities despite having the biggest watershed area. This can be attributed to the fact that Hiromi river has the least area of rice paddy, while Mima river which is apparently the most impacted of the activities has the biggest apportioned area for rice paddy.

# CHAPTER IV

# WATER QUALITY CHARACTERIZATION STUDIES

## 4.1 Study Site

The study site is a network of rivers located in southern Ehime Prefecture, Japan. It is located between latitudes 33°8' N and 33°20' N and between longitudes 132°34' E and 132°53' E. The rivers are classified as small (Nara, Mima, Hiromi) to large river (Shimanto), according to UNEP and WHO classification. Nara river flows into Mima river, Mima river flows into Hiromi river, and Hiromi river flows into the Shimanto river (**Fig. 4.1**).


Figure 4.1: Relative location of monitoring and sampling sites

The watershed characteristics of Nara, Mima and Hiromi rivers had been presented in Chapter III (**Table 3.1**). Shimanto river, on the hand, has a watershed area of 2,270 $km^2$, mainstream length of 196 km, and is in the $7^{th}$ stream order. Hiromi river drains into Shimanto river, in the latter's midstream portion and around 47 km from its mouth facing the Pacific Ocean. Shimanto river watershed, like the other three river watershed, is basically forested (74%) and with a meager arable area (8%). Approximately 63% of the arable land is apportioned to paddy rice production and the remaining area planted with seasonal vegetables and other crops.

There are eight sampling sites for the overall water quality monitoring, unlike that of suspended sediment transport study which has only three. An observation-*cum*-sampling site was established in each of the four rivers (same sampling sites in Nara, Mima and Hiromi rivers are the same for suspended sediment) and a sampling site approximately 1 kilometer downstream of each confluence. As the distance of Mima-Hiromi cnfluence is quite far from the Shimanto river, a sampling site (Site 6) was established at the downstream of Hiromi river just before its confluence with Shimanto river (**Fig. 4.1**). At sampling site No. 6, Hiromi river would have a main stream length of 56 km and a watershed area of 367 $km^2$.

The sampling sites were designed as to capture the effect of water quality of one river to the water quality of the bigger and draining river. As such, comparison and evaluation of the effect of water qualities of the tributaries would be more explicit and easier to analyze. This would also make conclusions and recommendations more objective and location-specific.

## 4.2 Data Monitoring, Sample Collection and Laboratory Analysis

The river discharge and water quality were periodically monitored for two years—from June 2010 to May 2012. The monitoring was conducted on normal flow, biweekly during the agricultural production season (April-September) and once a month during October-March period. The parameters, monitoring and analysis method, and standard value are summarized in **Table 4.1**. It is composed of river discharge and nine water quality parameters: the physico-chemical parameters $\Delta T$ (change in water temperature), pH, DO, $BOD_5$, Turb (turbidity) and TSS (total suspended solids); inorganic pollution indicators $NO_3$-N and $PO_4$-P; and bacteriological indicator FCB (fecal coliform bacteria).

Table 4.1: Water quality parameters and monitoring/laboratory analysis methods

| Parameters | Unit | Monitoring/Analysis Methods |
|---|---|---|
| Discharge, Q | $m^3/s$ | data logger |
| Turbidity, T | NTU | bench turbidimeter |
| Total Suspended Solids, TSS | mg/L | filtration-oven |
| Temperature, $\Delta T$ | $^0C$ | *in-situ* |
| pH | | *in-situ* |
| Dissolved Oxygen, DO Deficit | mg/L | *in-situ* |
| Biochemical Oxy. Demand, $BOD_5$ | mg/L | residual DO |
| Total Fecal Coliform Bacteria, FCB | colonies/100mL | cfu plate count |
| Nitrate, $NO_3$-N | mg/L | UV spectrophotometric |
| Phosphate, $PO_4$-P | mg/L | UV spectrophotometric |

*Note:* Laboratory analyses are based on APHA (1995) procedures

Discharge was determined by an established discharge rating curve and by monitoring the hourly river stage using a data logger. Physico-chemical water quality parameters (water temperature, pH, and DO) are monitored *in-situ* using a multi-parameter sensor probe (W-22XD Horiba), and water samples are manually collected for the analysis of other parameters (Turb, TSS, $BOD_5$, $NO_3$-N, $PO_4$-P, and FCB) in the Water Resources Laboratory, Ehime University. Temperature for every sampling site is measured twice: in the water collection site and in a similarly-conditioned site 1 mile upstream. The difference represents $\Delta$T. For DO, the DO deficit (instead of observed DO) was used in the analysis. DO deficit is found to have a more consistent correlation with BOD as it accounts the effect of photosynthetically-active organisms in the waters, as well as the effect of temperature and pressure due to non-ideal air/water equilibration. It is computed as the difference of the saturation DO and observed DO.

There were a total of 320 data sets (aggregate data) for every parameter during the monitoring period—40 from each sampling site.

## 4.3 Data Analysis Procedure

The overall water quality of the rivers is represented by WQI. It is a unitless number that consists of sub-index scores assigned to each parameter by comparing its measurement with parameter-specific rating curve, optionally weighted and combined into the final index (Chapman, 1992; Pesce and Wunderlin, 2000).

The water quality parameters used in the study were initially based on the National Sanitation Foundation Water Quality Index (Ott, 1978; Dunnette, 1979; Miller *et al.*, 1986) which is one of the popularly-used indices for general water quality evaluation as it is derived from a combination of physical, chemical, and bacteriological indicators (Karami *et al.*, 2009). However, a novel way of computing the WQI was adopted, *i.e.* the weight of each parameter ($W_i$) was differentiated to achieve location specificity, using Factor Analysis.

Factor Analysis (FA) was conducted to determine the water quality parameters that highly influence the water quality of the rivers by identifying the parameters that explain most of the variances of the system. In mathematical terms, Factor Analysis involves the following steps: (1) coding the variables $x_1, x_2, \ldots, x_n$, to have zero means and unit variance, (2) calculate the covariance matrix $\boldsymbol{C}$, (3) find the eigenvalues $\lambda_1, \lambda_2, \ldots, \lambda_n$ and the corresponding eigenvectors $a_1, a_2, \ldots, a_n$, (4) discard components that only account for a small proportion of the variation of the dataset, and (5) develop the factor loading matrix to infer principal parameters (Ouyang *et al.*, 2006). The Factor Analysis model can be expressed in the matrix notation;

$$\mathbf{x} = \boldsymbol{\mu} + \boldsymbol{\Lambda}\mathbf{f} + \boldsymbol{\upsilon} \quad (4.1)$$

where $\boldsymbol{\Lambda}=\{1_{ij}\}$ is a $p'k$ matrix of constants, called the matrix loadings; **f** is random vector representing the k common factors; and $\boldsymbol{\upsilon}$ is random vectors representing *p* unique factors associated with the original variables.

The common factors F1, F2,…, Fk are common to all variables and are assumed to have a mean equal to 0 and variance equal to 1. The unique factors are unique to $x_i$ and are also assumed to have a mean equal to 0 and are uncorrelated to the common factors. Equivalently, the covariance matrix S can be decomposed into a factor covariance matrix and an error covariance matrix;

$$\mathbf{S} = \boldsymbol{\Lambda}\boldsymbol{\Lambda}^{\mathbf{T}} + \boldsymbol{\Psi} \tag{4.2}$$

where $\boldsymbol{\Psi}$ = Var {u} and $\boldsymbol{\Lambda}^{\mathbf{T}}$ = transpose of $\boldsymbol{\Lambda}$. The diagonal of the factor covariance is called the vector of communalities, $h_i^2$, where $h_i^2 = \sum_{j=1}^{n} \lambda_{ij}^2$.

The FA was carried out on XLStat program software using parameter indexes and parameter values, with the parameter values log-transformed for normalization. VARIMAX rotation was conducted to reduce the factors into a single factor, describing the overall water quality and determining the factors that strongly influence the water quality.

Prior to the FA, a preliminary correlation analysis among parameters was conducted to check the suitability of FA, particularly the requirement of having a substantial amount of high correlations among variables—correlation coefficient of 0.3 or higher (Wackernagel, 1995). The correlations using aggregate data (**Table 4.2**) and data of each sampling sites (**Appendix 12-14**) show that more than half or a considerable count of the correlations are higher than 0.3, thus, meeting the requirement.

Table 4.2: Water quality parameters correlation by non-parametric Spearman analysis

| Parameters | ΔT | pH | Turb | TSS | DO Deficit | $BOD_5$ | $NO_3$-N | $PO_4$-P | FCB |
|---|---|---|---|---|---|---|---|---|---|
| **ΔT** | 1 | | | | | | | | |
| **pH** | 0.028 | 1 | | | | | | | |
| **Turb** | -0.054 | **-0.256** | 1 | | | | | | |
| **TSS** | **-0.125** | -0.021 | **0.634** | 1 | | | | | |
| **DO Deficit** | **-0.149** | **-0.285** | **-0.213** | **-0.125** | 1 | | | | |
| **$BOD_5$** | 0.023 | **0.126** | -0.092 | **0.135** | **0.307** | 1 | | | |
| **$NO_3$-N** | 0.034 | **-0.522** | **0.287** | **0.212** | **0.256** | 0.099 | 1 | | |
| **$PO_4$-P** | 0.005 | -0.075 | **0.550** | **0.457** | **-0.400** | **-0.291** | **0.303** | 1 | |
| **FCB** | 0.002 | **-0.260** | **0.589** | **0.400** | **-0.471** | **-0.396** | **0.217** | **0.679** | 1 |

*Note:* Values in boldface are different from 0 with a significance level $\alpha = 0.05$.

The results of FA using aggregated data are shown in **Tables 4.3** to **4.5** and **Figure 4.2**. Taking the results for the aggregated data as an illustrative explanation, the analysis extracted six principal factors and the variances due to the common factors and shared by the variables is approximately 64% (**Figure 4.2**). The eigenvalues for a given factor reflects the variances in all the water quality parameters which are accounted for by that factor. The scree plot of eigenvalues and variances of aggregated data showed that the first 3 factors have eigenvalues of approximately or greater than 1 and accounts for 58% of the total variances of the dataset (**Table 4.2**).

Table 4.3: Eigenvalues and variance of the principal factors

| **Descriptor** | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.81 | 1.53 | 0.93 | 0.39 | 0.13 | 0.01 |
| Variability (%) | 31.16 | 17.01 | 10.31 | 4.37 | 1.48 | 0.13 |
| Cumulative Variability (%) | 31.16 | 48.17 | 58.46 | 62.83 | 64.31 | 64.44 |

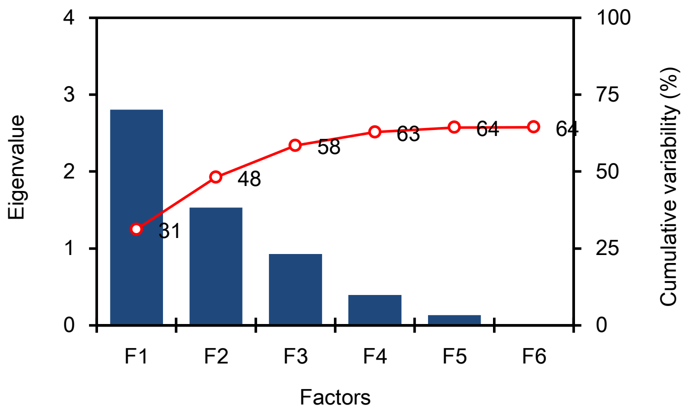



Figure 4.2: The scree plot of eigenvalues and variance, using aggregated data (*n=320*)

The first four factors could already explain the significant variances of all the water quality parameters. The factor loadings shown in **Table 4.4** are the correlation coefficient between the parameters and factors or the percentage variance explained by a factor in the parameter. The water quality parameters Turb, TSS, $PO_4$-P and FCB are highly correlated to the 1$^{st}$ factor which contributed to most of the variances of the system; hence, they are the parameters that most likely have the highest influence to the overall water quality. The pH, DO and $NO_3$-N is highly correlated to the 2$^{nd}$ factor, while $BOD_5$ to the 3$^{rd}$ factor, also indicating relative influence to the overall water quality to a certain degree. The $\Delta$T is highly correlated to the 4$^{th}$ factor which contributed only 3.59% to the variance, hence, has the least influence to the water quality. The FA results have slight difference when analyzing the data separately for each sampling site, especially to the parameters that are highly correlated to the 2$^{nd}$ and further-ranked factors (*refer to* **Appendix 7-11**).

The results of FA, considering the factor loadings of the different factors, had been interpreted only to the extent of variances of the parameters as correlated to the different factors. However, a more meaningful interpretation could be arrived at if the factors are further reduced, say, to a single factor; hence, the VARIMAX rotation. The single factor shows the variances contributed by each water quality parameter as correlated to a single factor—the overall water quality. In many cases, the derived single factor has the same factor pattern and the correlation of each parameter to the factor is either the same or higher (*refer to* **Appendix 7-11**).

Table 4.4: Factor loading of the four principal factors on aggregated data

| Water Quality Parameters | **Principal Factors** | | | |
|---|---|---|---|---|
| | **F1** | **F2** | **F3** | **F4** |
| ∆T | -0.016 | 0.073 | 0.112 | **-0.240** |
| pH | -0.286 | **0.583** | -0.377 | -0.249 |
| Turb | **0.754** | -0.084 | -0.178 | 0.125 |
| TSS | **0.665** | -0.089 | -0.654 | 0.099 |
| DO Deficit | -0.393 | **-0.667** | -0.095 | 0.206 |
| $BOD_5$ | -0.274 | -0.293 | **-0.468** | -0.178 |
| $NO_3$-N | 0.414 | **-0.749** | 0.148 | -0.366 |
| $PO_4$-P | **0.773** | 0.136 | 0.044 | -0.143 |
| FCB | **0.848** | 0.181 | 0.239 | 0.070 |

*Note:* Values in boldface show parameters having the highest weight in each factor.

Table 4.5: Factor loading of the derived single factor after VARIMAX rotation

| Parameter | Aggregate Data | River-Sampling Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| ∆T | -0.016 | -0.236 | **0.478** | **0.523** | 0.223 | -0.421 | 0.424 | 0.347 | 0.172 |
| pH | -0.286 | -0.257 | -0.205 | -0.426 | 0.073 | -0.167 | 0.192 | 0.120 | -0.176 |
| Turb | **0.754** | **0.655** | 0.433 | **0.792** | **0.664** | **0.731** | **0.532** | **0.732** | **-0.623** |
| TSS | **0.665** | **0.676** | 0.057 | **0.734** | 0.262 | **0.432** | 0.150 | **-0.541** | 0.434 |
| DO Deficit | -0.393 | **-0.486** | **-0.855** | -0.326 | **-0.740** | **-0.665** | **-0.724** | **-0.783** | **0.809** |
| $BOD_5$ | -0.274 | **-0.540** | **-0.710** | **-0.539** | **-0.464** | **-0.560** | **-0.575** | **-0.673** | **0.706** |
| $NO_3$-N | 0.414 | -0.035 | -0.101 | 0.164 | -0.396 | -0.170 | -0.361 | 0.096 | 0.054 |
| $PO_4$-P | **0.773** | **0.785** | **0.481** | **0.640** | **0.720** | **0.720** | **0.694** | **0.539** | **-0.572** |
| FCB | **0.848** | **0.887** | **0.727** | **0.812** | **0.778** | **0.861** | **0.766** | **0.750** | **-0.777** |

*Note:* Values in boldface shows the primary and important/highly-weighted parameters.

The results of the VARIMAX rotation for aggregated data shows that the overall water quality tends to be highly influenced by FCB, $PO_4$-P, Turb, and TSS (**Table 4.4**). However, when considering results for each sampling site, DO and $BOD_5$ may also have influence to the overall water quality. These parameters are given more weight on the computation of the WQI. The mean of the resulting factor loadings of the single factor by VARIMAX rotation is then used to rank and quantify the importance of the parameters to the over water quality, as represented by WQI. The parameters were ranked based on a devised ranking procedure translating the factor loading (FL) into a scale of 1 to 4, *i.e.* 4 ($FL \geq 0.7$), 3 ($0.7 > FL \geq 0.4$), 2 ($0.4 > FL \geq 0.2$), 1($FL < 0.2$). Thereafter, the ranks were converted to weight percentages. In Sites 1, 3, and 5, Turb and TSS were strongly-correlated (*refer to* **Table 4.11**), hence, they are harmonically-averaged to prevent double weighing (Hallock, 2002).

Table 4.6: Water quality parameters' rank and index weight

| Parameters | Sites 2,4,6,7,8 | | Sites 1,3,5 | |
|---|---|---|---|---|
| | Rank[1] | $W_i$ [2] | Rank[1] | $W_i$ [2] |
| ΔT | 2 | 8% | 2 | 9% |
| pH | 2 | 8% | 2 | 9% |
| Turb | 3 | 12% | ]3 | ]14% |
| TSS | 3 | 12% | | |
| DO Deficit | 3 | 12% | 3 | 14% |
| $BOD_5$ | 3 | 12% | 3 | 14% |
| $NO_3$-N | 1 | 4% | 1 | 4% |
| $PO_4$-P | 4 | 16% | 4 | 18% |
| FCB | 4 | 16% | 4 | 18% |

*Notes:* [1] Based on factor loading by Factor Analysis [2] Index Weight, $W_i = (Rank_i / \sum Ranks)*100$

The mathematical expression and final rating for WQI is given by,

$$WQI = \sum_{i=1}^{9} I_i W_i = I_{\Delta T}(0.08) + I_{pH}(0.08) + I_{Turb}(0.12) + I_{TSS}(0.12) + I_{DO}(0.12) + I_{BOD_5}(0.12) + I_{NO_3-N}(0.04) + I_{PO_4-P}(0.16) + I_{FCB}(0.16) \quad (4.3)$$

for Sites 2, 4, 6, 7, and 8, and

$$WQI = \sum_{i=1}^{9} I_i W_i = I_{\Delta T}(0.09) + I_{pH}(0.09) + I_{Turb/TSS}(0.14) + I_{DO}(0.14) + I_{BOD_5}(0.14) + I_{NO_3-N}(0.04) + I_{PO_4-P}(0.18) + I_{FCB}(0.18) \quad (4.4)$$

for Sites 1, 3, and 5,

where $I_i$ is the index value for $i_{th}$ water quality parameter and $W_i$ is the weight of each parameter. The index value is a standardized rating value for each parameter with range 0~100 (0 for worst and 100 for best quality) based on 'Q-curves'. Q-curves are established weight curve charts translating water quality parameter values (abscissa) into water quality rating of 0~100 (ordinate), with 0 representing worst and 100 best parameter value (*refer to* **Appendix Fig. 6**).

A correlation analysis, using the non-parametric Spearman rank correlation ($r_s$), was conducted using actual parameter values and parameter index values to determine the significantly correlated parameters and the parameters which are highly correlated to WQI. Non-parametric correlation analysis was used since the data failed to meet the requirement of normality (*refer to Sk values in* **Table 4.7**).

An Agglomerative Hierarchical Cluster Analysis using complete linkage method was conducted to assess the water quality spatial variation, that is, similarity of the water quality index among sampling sites. Cluster Analysis has been popularly used to display unsupervised pattern recognition to help group objects into classes on the basis of similarities (Vega *et al.*, 1998; Helena *et al.*, 2000; Singh *et al.*, 2004; Panda *et al.*, 2006). Moreover, an ANOVA with pairwise mean comparison analysis was done to determine any significant difference among the WQI of the river-sampling sites at different seasons. The results are also used to find any concurring findings with that of the Cluster Analysis.

All data analyses were conducted with the aid of XLStat program software version 2011.

## 4.4 Results and Discussion

### 4.4.1 Water Quality Parameters and Trend Analysis

The monitored data of the water quality parameters, presented in **Figs. 4.3** to **4.5**, shows a more or less similar trend in most of the sampling sites, regardless of the season or time of monitoring. And such trend is in accordance with the interpretation using the mean values, as shown in **Table 4.7**. Among the parameters, $\Delta$T and TSS show the most erratic monitored data but which, when averaged, would still lead to the same interpretation as the other parameters. On the other hand, pH and the oxygen-related parameters (*i.e.* DO deficit and $BOD_5$) shows the least varied data and where all sites have almost the same variation and trend. Moreover, other than TSS, Turb and FCB, the water quality parameters are within the range of standard value for a good river quality.

The sampling Sites 1, 2, and 3 show higher values of T, Turb, TSS, $BOD_5$, $NO_3$-N, $PO_4$-P, and FCB, indicating an apparent lower water quality. Conversely, sampling Sites 7 and 8 show the lowest values on these parameters, an indicator of apparent better water quality. And, in most cases among 'in-between sites', Site 4 shows lower values than Sites 5 and 6, with Site 6 having lower values than Site 5 most of the time.

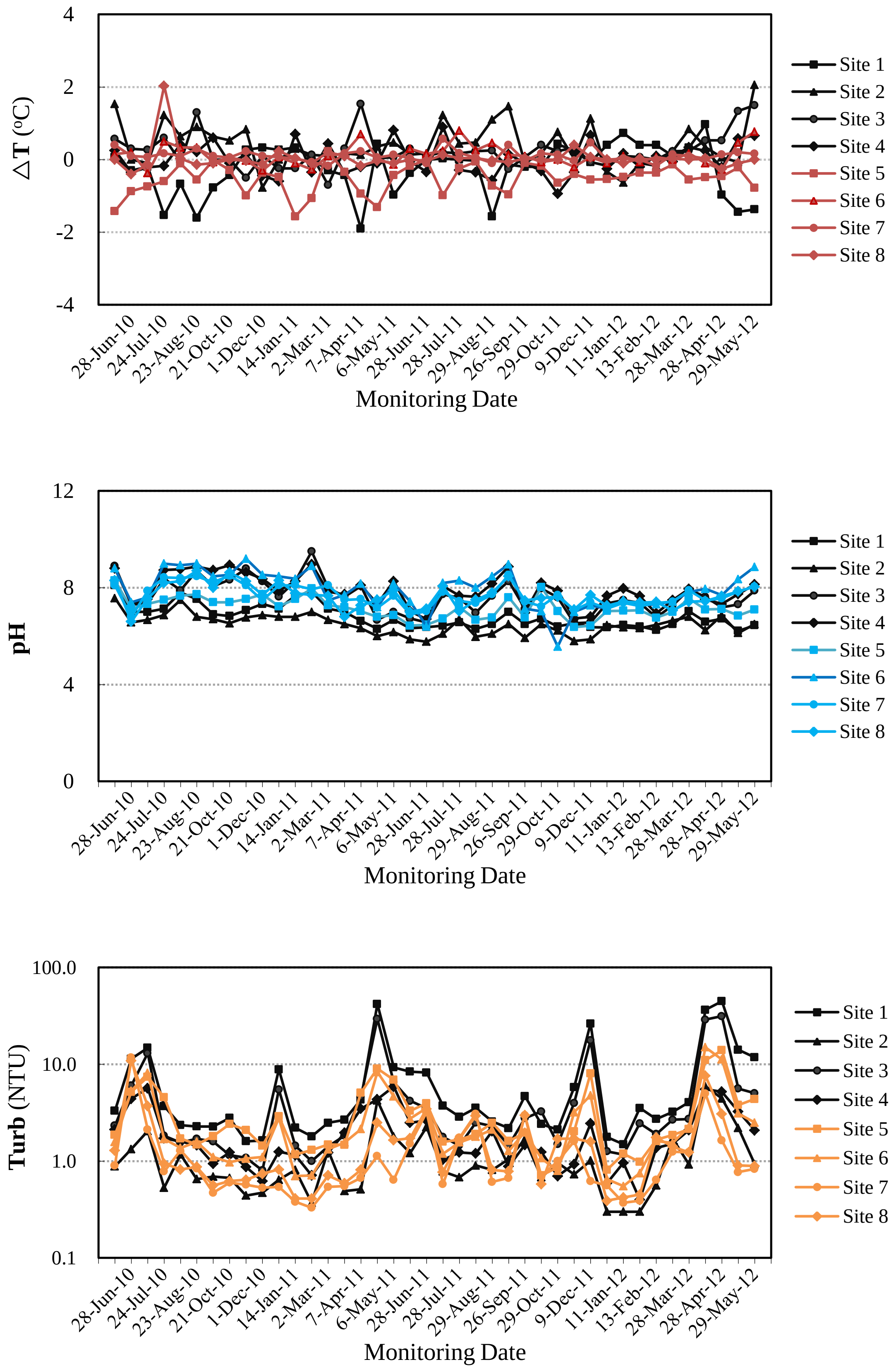



Figure 4.3: Monitored data for ∆T, pH and Turbidity from June 2010 to May 2012 ($n$ = *40*)

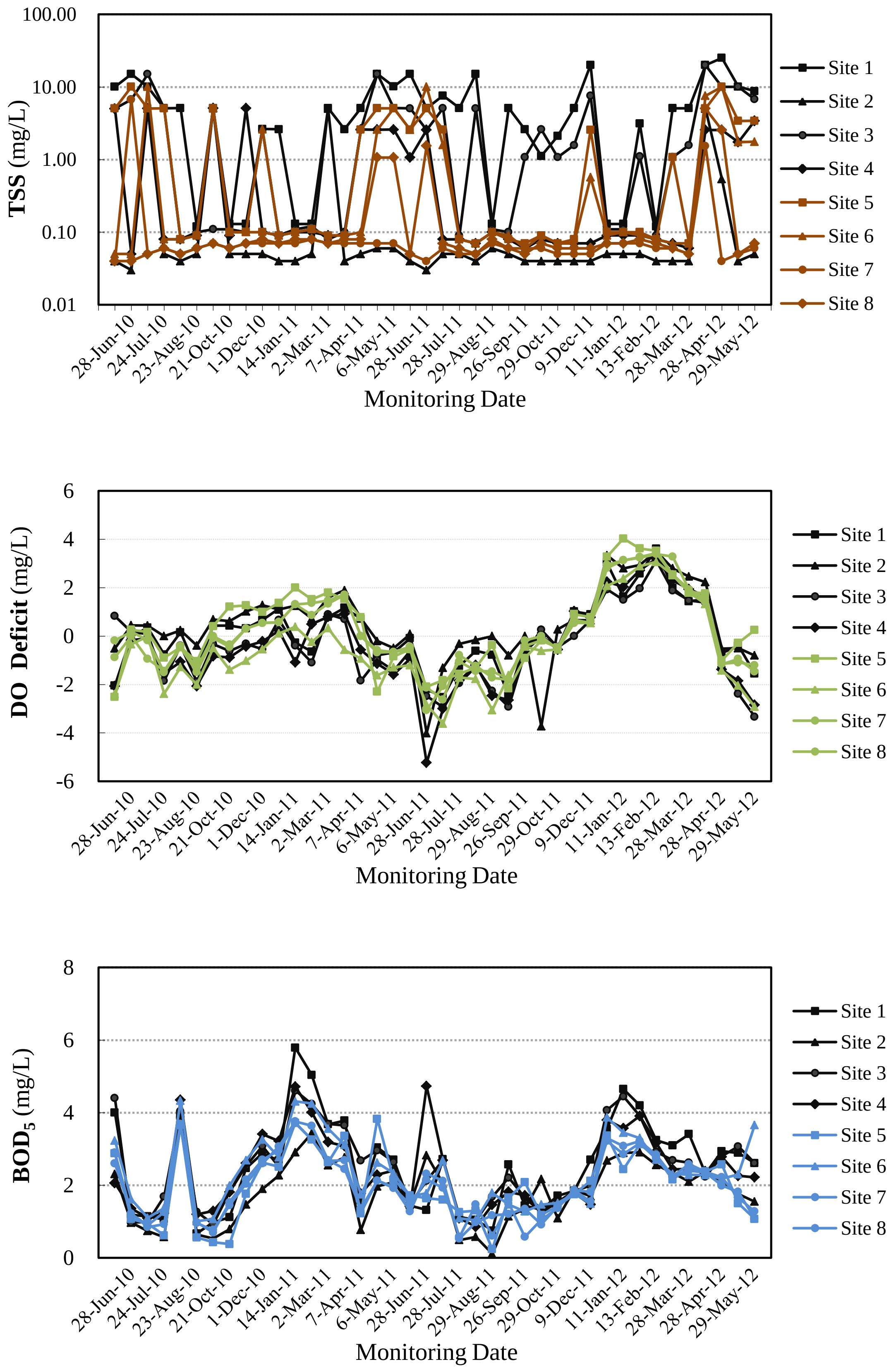



Figure 4.4: Monitored data for TSS, DO and $BOD_5$ from June 2010 to May 2012 (*n* = *40*)

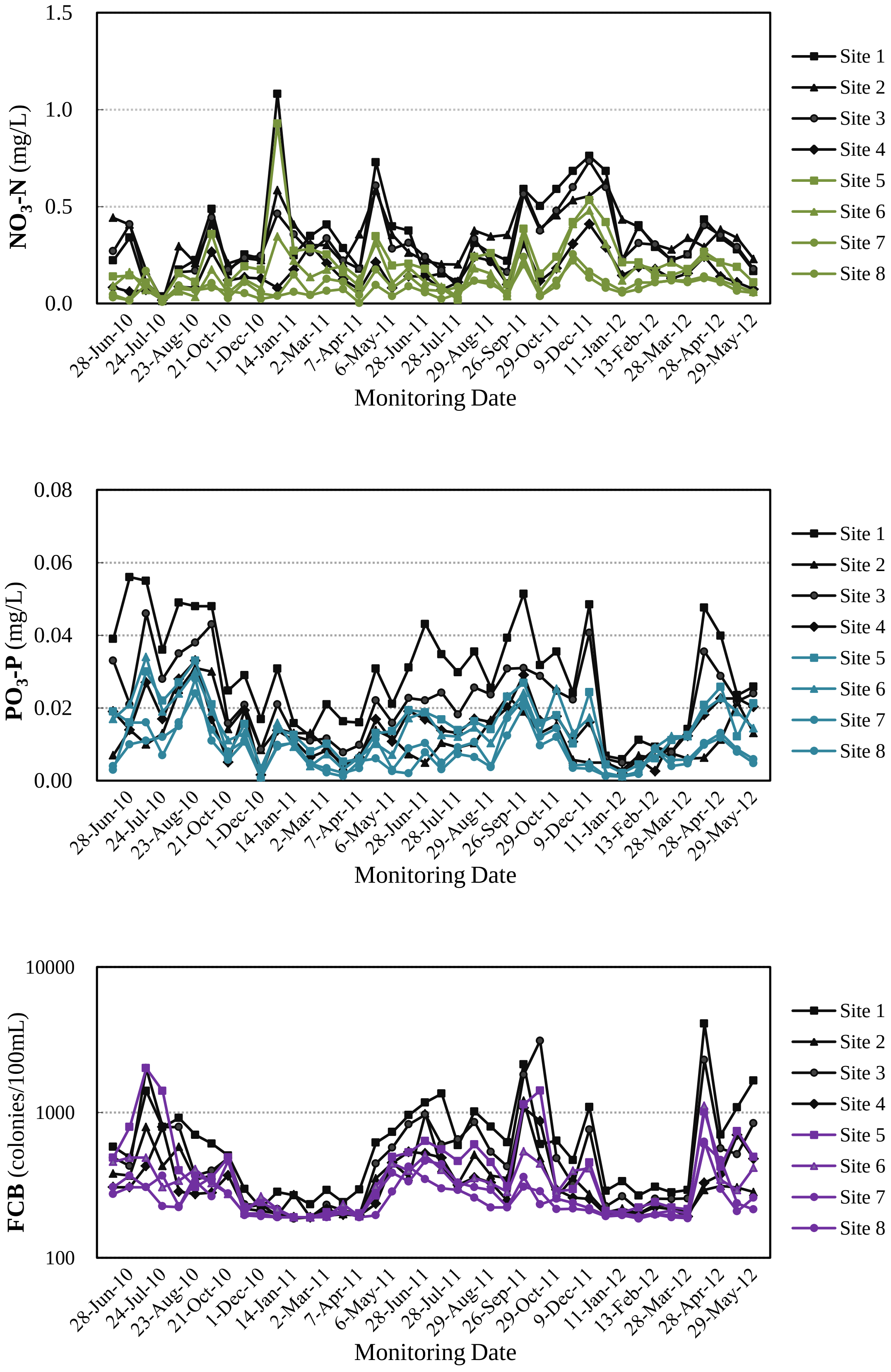



Figure 4.5: Monitored data for $NO_3$-N, $PO_4$-P and FCB from June 2010 to May 2012 (*n* = *40*)

Table 4.7: Descriptive statistics of river discharge and water quality parameters

| Parameters | Stat | Aggregate (*n=320*) | River- Sampling Sites *(n = 40)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Q | Mean | 15.8 | 1.3 | 0.8 | 2.5 | 4.1 | 6.6 | 13.0 | 42.5 | 55.5 |
| | CV | 2.4 | 1.3 | 1.2 | 1.2 | 0.8 | 0.9 | 0.9 | 1.4 | 1.3 |
| | Sk | 4.9 | 3.8 | 2.3 | 3.0 | 1.7 | 2.3 | 2.3 | 2.4 | 2.2 |
| $\Delta T$ | Mean | 0.34 | 0.54 | 0.50 | 0.36 | 0.35 | 0.48 | 0.22 | 0.14 | 0.11 |
| | CV | 1.1 | 0.9 | 0.9 | 1.1 | 0.7 | 0.7 | 0.9 | 0.9 | 1.6 |
| | Sk | 1.1 | 1.2 | 0.8 | 1.9 | 0.9 | 0.6 | 1.4 | 1.6 | 3.7 |
| pH | Mean | 7.4 | 6.8 | 6.5 | 7.7 | 7.9 | 7.2 | 8.0 | 7.7 | 7.7 |
| | CV | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | Sk | 0.2 | 1.0 | 0.4 | 0.4 | 0.1 | 0.3 | 0.1 | 0.2 | 0.1 |
| Turb | Mean | 3.2 | 7.9 | 1.2 | 5.3 | 2.1 | 3.3 | 2.8 | 1.4 | 1.7 |
| | CV | 1.7 | 1.4 | 1.0 | 1.4 | 0.7 | 0.9 | 1.1 | 1.4 | 1.2 |
| | Sk | 4.8 | 2.4 | 2.5 | 2.5 | 1.3 | 1.9 | 2.5 | 4.2 | 3.2 |
| TSS | Mean | 2.0 | 6.5 | 0.6 | 3.5 | 1.1 | 2.0 | 1.6 | 0.3 | 0.3 |
| | CV | 1.9 | 1.0 | 2.7 | 1.3 | 1.5 | 1.3 | 1.8 | 4.0 | 2.7 |
| | Sk | 2.8 | 1.1 | 2.6 | 1.8 | 1.4 | 1.4 | 2.0 | 5.7 | 4.0 |
| DO Deficit | Mean | -0.02 | 0.10 | 0.50 | -0.42 | -0.45 | 0.38 | -0.55 | 0.15 | 0.14 |
| | CV | 8.6 | 14.0 | 3.1 | 3.6 | 3.9 | 4.4 | 3.0 | 10.5 | 11.4 |
| | Sk | 0.2 | 0.3 | -0.5 | 0.1 | -0.1 | 0.3 | 0.5 | 0.5 | 0.6 |
| $BOD_5$ | Mean | 2.2 | 2.5 | 1.8 | 2.5 | 2.4 | 2.0 | 2.3 | 2.0 | 2.0 |
| | CV | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 |
| | Sk | 0.5 | 0.5 | 0.1 | 0.4 | 0.6 | 0.1 | 0.5 | 0.2 | 0.3 |
| $NO_3$-N | Mean | 0.22 | 0.36 | 0.36 | 0.32 | 0.16 | 0.24 | 0.17 | 0.08 | 0.10 |
| | CV | 0.8 | 0.6 | 0.3 | 0.5 | 0.5 | 0.7 | 0.6 | 0.6 | 0.5 |
| | Sk | 1.5 | 1.4 | 0.5 | 1.0 | 1.0 | 2.2 | 1.1 | 1.4 | 0.8 |
| $PO_4$-P | Mean | 0.02 | 0.03 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| | CV | 0.9 | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 | 1.4 | 0.7 | 0.6 |
| | Sk | 4.8 | 0.1 | 1.1 | 0.3 | 0.2 | 0.2 | 5.3 | 1.6 | 0.7 |
| FCB | Mean | 435 | 756 | 365 | 638 | 351 | 495 | 339 | 260 | 276 |
| | CV | 1.0 | 0.9 | 0.6 | 1.0 | 0.6 | 0.8 | 0.5 | 0.4 | 0.3 |
| | Sk | 4.4 | 3.1 | 2.4 | 2.4 | 1.9 | 2.1 | 2.7 | 1.9 | 1.6 |

For a better and more conclusive interpretation, the monitored data of the water quality parameters (including river discharge) were analyzed for its basic statistics. The coefficient of variation (CV) was computed to determine the dispersion of data, at a normalized value, for easier comparison with other parameters. Skewness (Sk), on the other hand, indicates the normality or non-normality of the data distribution.

The descriptive statistics of the water quality parameters for the aggregated and respective sampling sites data are summarized in **Table 4.7**. River discharge, indicative of the size of watershed area, shows that Site 2 has the smallest flow and Site 8 the biggest. Site 3, which is the confluence of Sites 1 and 2, do not reflect a sum of flows of the two sites as Site 1 is approximately 1 km and Site 2 about 1.6 km from their confluence. The drainage outfalls between the sites and confluence contributed 15-20% of the resulting flow. On the other hand, Sites 5 reflected a sum of flows of Sites 3 and 4, and Site 8 reflected a sum of flows of Sites 6 and 7, as the sites are located proximately before the confluence.

Except for pH and DO deficit, the apparent general trend of the mean values is: relatively high at Site 1, decreases at Site 3 due to the influx of cleaner flow from Site 2, and further decreases at Site 5 due to cleaner discharge from Site 4. Site 6 is of considerable distance from Site 5 (approximately 19 kilometers) and the decrease of values in most of its parameters suggests an influx of cleaner discharge from some tributaries along the distance from Site 5 to Site 6. The parameter values in Shimanto river (Sites 7 and 8) are either the same (pH, TSS, DO, $BOD_5$, $PO_4$-P) or slightly increased (Turb, $NO_3$-N, FCB), indicating a very slight undesirable effect of the flow from Hiromi river (Site 6).

All parameters, except for Turb, TSS and DO deficit, have CV values less than 100% which indicates fewer or no extreme values. The physico-chemical parameter pH (*CV=0.10*) has the least variation, while DO deficit has the highest. Further, none of the parameters is normally distributed as indicated by positive Sk values (skewed to the right) indicating mode values higher than mean values, thus, requiring a non-parametric tests for correlation and other analyses (McBride, 2005).

The seasonal trend and range of the water quality parameter values are represented in Box-Whisker plots (**Fig. 4.6**). The box plots provide a visual impression of the location and shape of the underlying distributions of the data set (Vega *et al.*, 1998; McBride, 2005). Box plots with longer upper whiskers and upper box indicate that the distribution is skewed toward higher concentrations and that extremely high values were recorded: such as the case of $\Delta T$ during spring-summer seasons, Turb during spring, TSS during spring-summer, $NO_3$-N during fall-winter season, $PO_4$-P during spring to fall, and FCB during spring-summer.

As indicated by wider box and longer whiskers (particularly upper box and whiskers), Turb and TSS had the widest range of values within season, especially during spring and summer seasons as compared to during fall and winter seasons.

The box plots also indicate seasonal differences. The parameters $PO_4$-P and FCB showed relatively low values at spring season which increases through summer, decreases or maintains at fall, and decreases during winter. This could be partly attributed to the peak of agricultural activities during summer and the rainfall-typhoon occurrences during fall which increase pollution flux in the rivers through runoff and drainage. Conversely, DO deficit and $BOD_5$ are high during spring, decreases during summer and fall, and increases again at winter. For DO, this may be partly because of the fact that as water temperature increases the solubility of gases, including oxygen, decreases (Tebbutt, 1992); and photosynthetic activities of phytoplankton, which releases oxygen, causes DO oversaturation and resulting to negative values for DO deficit.

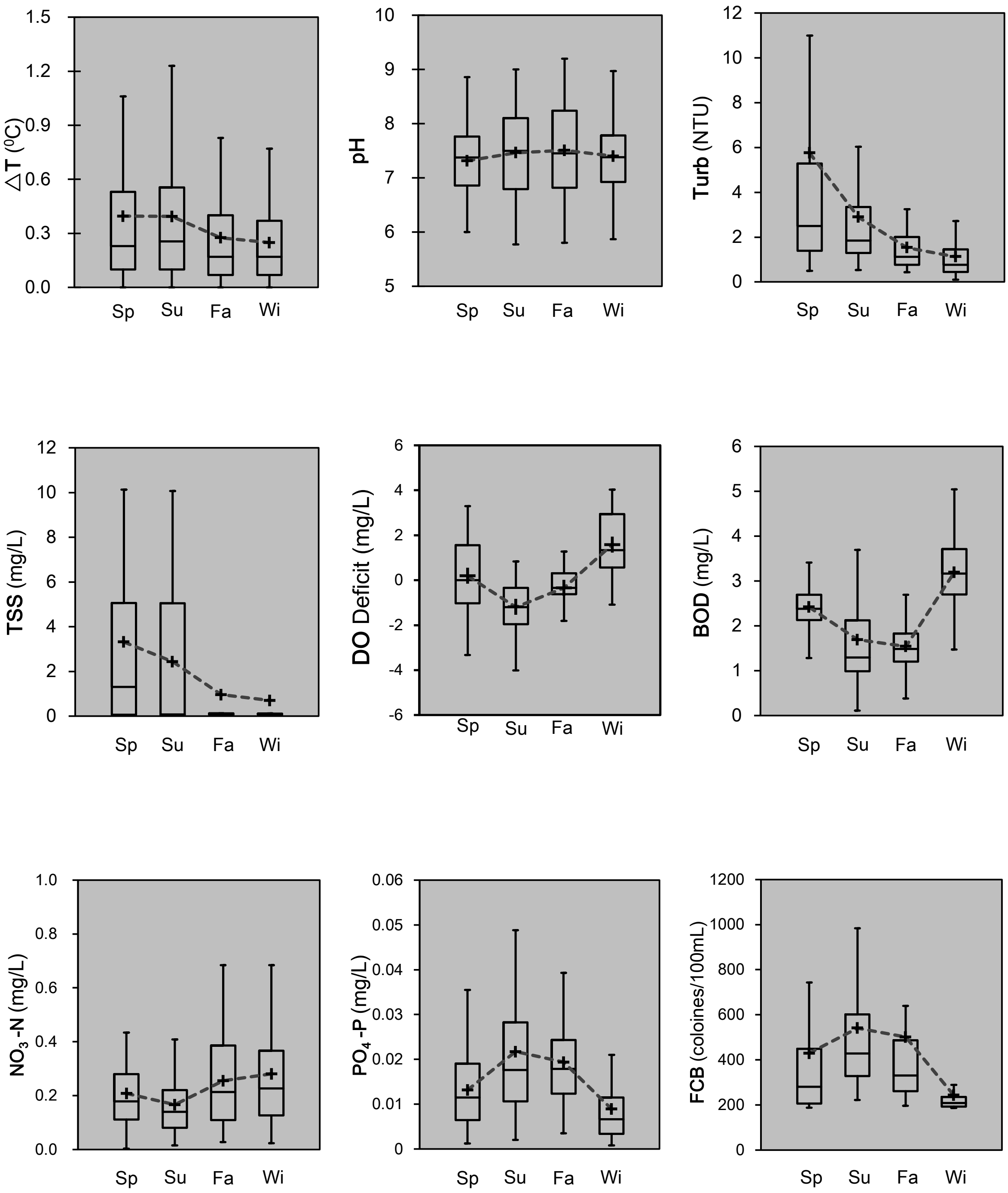



Figure 4.6: Box-whisker plots showing seasonal variations of the water quality parameters

(*Broken line connects the mean values. The upper box represents the 3^rd^ quartile and the lower box the 1^st^ quartile. The upper and lower whiskers locate the maximum and minimum values,respectively. Sp- spring, Su- summer, Fa- Fall, Wi- winter*)

On the other hand, Turb and TSS are high during spring and continue to decrease until winter. This could be partly attributed to the land preparation during April and May which produce a lot of sediment, especially the drainage water from paddy fields after soil paddling in preparation for rice transplanting. Other agricultural activities, done from summer to fall, produce little or no drainage water; while there are no such activities during winter. The $\Delta T$, pH, and $NO_3$-N have apparently insignificant seasonal change, indicating lesser influence on the general water quality, as manifested in the Factor Analysis results (**Table 4.4-4.5** and **Appendix 7-11**).

### 4.4.2 Water Quality Index and Parameter Correlation

The river water quality, as represented by WQI, is summarized in **Table 4.8** and depicted in **Figs. 4.7** and **4.8**. It shows seasonal differences and the trend shows low water quality during spring and winter, while slightly better during summer and best during fall (as supported later by ANOVA and pairwise mean comparison analysis). Spring correspond to the start of agricultural activities, especially land preparation and rice transplanting. Winter corresponds to the least-rainfall and low-discharge period, and municipal effluents could have a greater effect on the water quality. Thus, seasonal changes in the water quality of the river/sampling-sites are apparently affected by land-use and environment factors.

Table 4.8: Aggregate and seasonal WQI means of the different sampling sites

| Data Period | River- Sampling Sites *(n = 40)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Aggregate | 77 | 80 | 78 | 79 | 79 | 79 | 81 | 81 |
| Spring[b] | 75 | 80 | 76 | 79 | 78 | 78 | 81 | 81 |
| Summer[b] | 78 | 81 | 78 | 80 | 80 | 79 | 82 | 81 |
| Fall[a] | 80 | 81 | 80 | 81 | 81 | 81 | 83 | 83 |
| Winter[b] | 76 | 79 | 77 | 79 | 77 | 79 | 80 | 80 |

*Note:* Same letter superscript among season shows no significant difference.

The supplementary pairwise mean comparison analysis conducted on the seasonal WQI values shows that spring, summer and winter WQIs are not significantly different from each other. The fall WQIs, as also the highest values, is significantly different from the WQIs of the other three seasons (**Table 4.8** seasonal superscripts).

Among the sampling sites, Site 1 has the lowest WQI values, indicating the 'worst' water quality. On the other hand, Sites 7 and 8 registered the highest WQI values, indicating the 'best' water quality which is expected as the two sites are located in the Shimanto river, representing before and after confluence with Hiromi river, respectively.

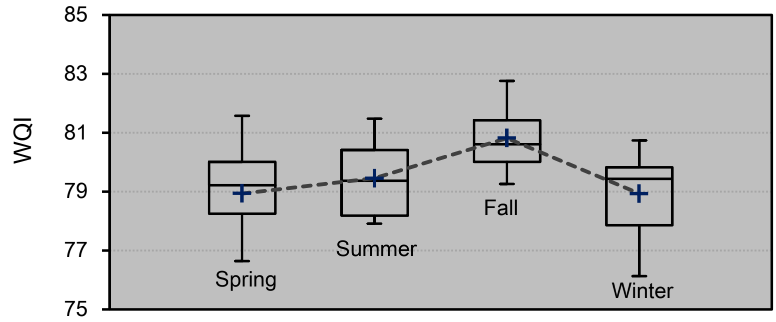



Figure 4.7: Box-whisker plots and seasonal trend of the WQI values

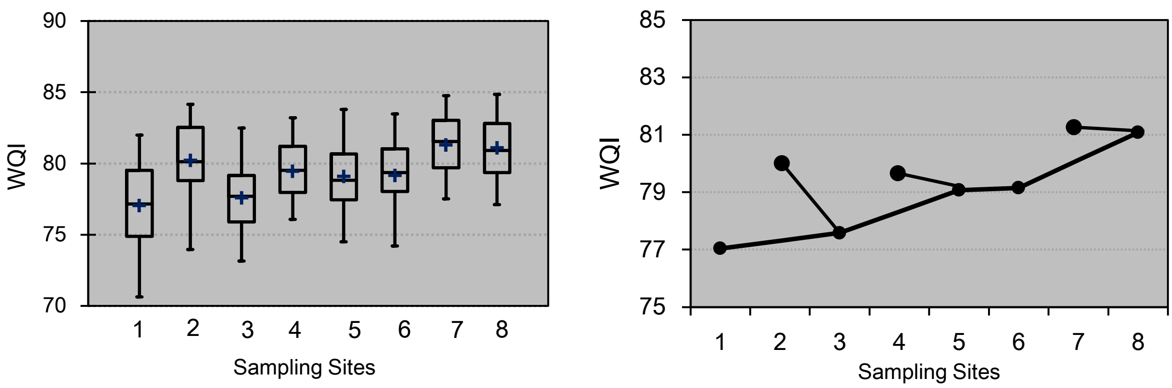



Figure 4.8: Box-whisker plots of the WQI values (‘**+**’ mean values) and general trend of water quality in river-sampling sites, showing the effect of merging at confluences

The box plot of WQI values (**Fig. 4.8**) shows that the sampling sites have generally the same range of high values, as shown by the extent of upper whiskers. On the other hand, Sites 1, 2 and 6 have some very low WQI values, as indicated by longer lower whiskers; and these sampling sites have very low WQI values during spring season.

Considering overall water quality using aggregated data, the effect of flow from tributaries is depicted in **Fig. 4.8**. River-sampling sites with better water quality (Sites 2, 4, and 7) improved the water quality of the draining rivers, at their confluence (Sites 3, 5, and 8). The water quality of Hiromi river (Site 4) slightly decreased upon the inflow of Mima river (Site 3). Hiromi river with its water quality further decreased at Site 6, slightly affected (decreased) the water quality of Shimanto river (Site 7 → Site 8). In this case, the use of WQI clearly indicated the effect of tributaries with apparently lower quality to the bigger river where it ultimately flows.

The correlation analyses presented in **Tables 4.9** and **4.10**, using the non-parametric Spearman rank correlation, showed no significant difference when correlating WQI with either parameter indices or parameter values, though, the WQI-parameter index values correlation (**Table 4.9**) gives slightly betterr correlation coefficient values and an easier interpretable results. It showed more highly correlated parameters when analysis is done seasonally, indicating significant seasonal differences. Considering data in each sampling sites, WQI correlates only with physico-chemical parameters DO and $BOD_5$. And, considering seasonal data, WQI correlates best with parameters Turb, TSS, FCB and $PO_4$-P; relatively good with DO deficit, $BOD_5$ and $NO_3$-N and; and the least with ∆T and pH.

Table 4.9: Significant correlations between WQI and parameter values
(Using Spearman correlation coefficient, $r_s$)

| Parameter | Season | | | | Rivers-Sampling Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sp | Su | Fa | Wi | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| ∆T | | | | | ***-0.409*** | | | ***-0.441*** | | | | |
| pH | | | | | ***0.459*** | ***0.482*** | | ***0.428*** | | | | |
| Turb | **-0.757** | | ***-0.317*** | ***-0.414*** | ***-0.412*** | | | | | | | |
| TSS | **-0.684** | ***-0.338*** | ***-0.314*** | **-0.532** | | | | | | | | |
| DO | | **0.438** | ***0.342*** | | | | | | | ***0.454*** | | |
| $BOD_5$ | **-0.530** | **-0.733** | **-0.598** | | ***-0.563*** | **-0.705** | ***-0.526*** | ***-0.545*** | **-0.755** | ***-0.470*** | **-0.741** | **-0.655** |
| $NO_3$-N | **-0.568** | | | ***-0.468*** | | | | | | | | |
| $PO_4$-P | **-0.672** | ***-0.371*** | ***-0.379*** | | | ***0.469*** | | | | | | |
| FCB | **-0.680** | **-0.424** | ***-0.342*** | ***-0.350*** | | | | | | | | |

*Note:* Values in boldface-italics are significant at $\alpha = 0.01$, in boldface $\alpha < 0.0001$.

Table 4.10: Significant correlations between WQI and parameter indexes
(Using Spearman correlation coefficient, $r_s$,)

| Parameter | Season | | | | Rivers-Sampling Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sp | Su | Fa | Wi | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| ∆T | ***0.383*** | | | | | | | | | | | |
| pH | ***0.318*** | **0.539** | | | ***0.543*** | ***0.478*** | | ***0.512*** | ***0.436*** | ***0.587*** | | |
| Turb | **0.752** | | ***0.307*** | ***0.421*** | ***0.422*** | | | | | | | |
| TSS | **0.726** | ***0.275*** | | ***0.374*** | ***0.345*** | | | | | | | |
| DO | ***0.340*** | **0.470** | **0.299** | | ***0.417*** | ***0.468*** | ***0.439*** | ***0.524*** | ***0.568*** | ***0.502*** | ***0.537*** | ***0.568*** |
| $BOD_5$ | **0.539** | **0.719** | **0.597** | | ***0.558*** | **0.703** | ***0.532*** | ***0.542*** | **0.756** | ***0.481*** | **0.750** | **0.643** |
| $NO_3$-N | ***0.275*** | | | | | | | | | | | |
| $PO_4$-P | **0.590** | ***0.339*** | ***0.368*** | | | | | | | | | |
| FCB | **0.692** | **0.426** | ***0.353*** | ***0.399*** | | | | | | | | |

*Note:* Values in boldface-italics are significant at $\alpha$ =0.01, in boldface $\alpha < 0.0001$.

During spring season, most water quality parameters are highly and significantly correlated to WQI, indicating a high variation of the parameters during such season and which could also have had considerably affected the overall water quality. Only FCB and TSS are highly and significantly correlated at all season; and Turb, $PO_4$-P, and $BOD_5$ in most seasons (three seasons).

The results of the correlation analysis, generally, coincide with the Factor Analysis results (**Table 4.4-4.5** and **Appendix 7-11**) and the devised ranking for the water quality parameters (**Table 4.6**). Parameters Turb, TSS, FCB and $PO_4$-P, which correlated best to WQI, have ranks 3, 3, 4 and 4, respectively. Moreover, both DO deficit and $BOD_5$, which are also considerably correlated to WQI, have ranks 3. Hence, Factor and Correlation Analyses could be used and better conducted simultaneously to verify respective results, thereby, leading to a more conclusive interpretation of the data.

Table 4.11: Highly-significant correlated parameters ( $r_s \geq 0.6$, $\alpha < 0.0001$) of the sampling sites

| River-Sampling Sites | | | | | | | |
|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| TSS:Turb[a] | FCB:DO[b] | TSS:Turb[a] | FCB:$PO_4$-P[b] | TSS:Turb[b] | FCB:Turb[b] | FCB:DO[b] | FCB:DO[b] |
| FCB:$PO_4$-P[b] | | FCB:$PO_4$-P[a] | | $PO_4$-P:DO[b] | FCB:$PO_4$-P[b] | | |
| | | Turb:pH[b] | | FCB:$PO_4$-P[b] | | | |

*Note:* [a] (0.8 ≥ $r_s$ > 0.7), [b] (0.7 ≥ $r_s$ > 0.6)

Table 4.12: Highly-significant correlated parameters ( $r_s \geq 0.6$, $\alpha < 0.0001$) using aggregate and seasonal data

| Aggregate | Season | | | |
|---|---|---|---|---|
| | **Spring** | **Summer** | **Fall** | **Winter** |
| TSS:Turb[b] | TSS:Turb[*] | TSS:Turb[b] | $NO_3$-N:pH[a] | TSS:Turb[b] |
| FCB:$PO_4$-P[b] | $NO_3$-N:pH[b] | $PO_4$-P:TSS[b] | | FCB:Turb[b] |
| | $PO_4$-P:Turb[a] | | | |
| | $PO_4$-P:TSS[b] | | | |
| | FCB:Turb[a] | | | |
| | FCB:TSS[b] | | | |
| | FCB:$PO_4$-P[a] | | | |

*Note:* [*] ($r_s$ > 0.8), [a] (0.8 ≥ $r_s$ > 0.7), [b] (0.7 ≥ $r_s$ > 0.6)

The correlation analysis among parameters showed high and significantly correlation between TSS:Turb in Sites 1, 3 and 5; FCB:$PO_4$-P in Sites 1, 3, 4, 5 and 6; FCB:DO in Sites 2 and 8; and Turb:pH, $PO_4$-P:DO and FCB:Turb in Sites 3, 5 and 6, respectively (**Table 4.11**). The correlation analysis using seasonal data shows that parameters are better correlated during spring, indicating a similar high variation of data in most parameters. And with reference to the highly correlated parameters of aggregated data, it appears that the parameters which correlate best with other parameters are Turb, TSS, FCB and $PO_4$-P. Further, it is observed that in river-sampling sites with better water quality (Sites 2, 4 and 8), there are very few highly-correlated parameters, suggesting a relatively independent variation among parameter values and more dependence on the river discharge and other environmental factors.

### 4.4.3 Cluster Analysis and Water Quality Spatial Variation

The Agglomerative Hierarchical Cluster Analysis was done using the WQI of each sampling sites (*n=40*). The analysis was performed using an automatic truncation option, which is based on the entropy of the given set of data and tries to create a number of significant homogenous group. The dendograms shows the sampling sites as grouped by the algorithm based on the similarity (Euclidian distance) of water quality indices (Massart and Kaufman, 1983). It also shows the clusters' weight (number of leaf), compactness (the distance that the cluster come into existence), and distinctness (distance from the point of existence to the point at which it is aggregated to a larger cluster) (Stockburger, 1997).

Results of Cluster Analysis (**Fig. 4.9**) were found in accordance with the ANOVA and pairwise mean comparison analysis by Duncan Multiple Range Test (DMRT) (**Table 4.13**); albeit with few inconsistencies. By definition, the sites within a cluster is said to have similar level of water quality. The cluster or sub-cluster which is more compact (longer lines of existence) and more distinct (longer distance from node to merging) are more similar in water quality than the others (Stockburger, 1997).

The dendogram of the aggregated data shows two distinct significant clusters: *Cluster I* (Sites 6, 4, 2, 8 and 7) and *Cluster II* (Sites 3, 1 and 5). Except for the inclusion of Site 5 in the 'b' group, the clustering is somehow in accordance with the ANOVA and pairwise mean comparison analysis where Sites 7 and 8 (Group 'a') are not significantly different and so with Sites 2, 4, and 6 (Group 'b') (**Table 4.13)**. Disregarding Site 5, Groups 'a' and 'b' formed *Cluster I* while Group 'c' formed *Cluster II*. The sampling Sites 7 and 8 formed a sub-cluster in *Cluster I* and is, in fact, the most distinct sub-cluster—indicating the most similar WQI. However, between the two clusters, *Cluster II* is more distinct than *Cluster I*.

The result of the cluster analysis for each season is slightly different from the aggregated data. Spring and Fall seasons consist of two distinct clusters while Summer and Winter seasons have three distinct clusters. Considering the results of the analysis using aggregated and seasonal data, it is apparent that only the sub-cluster of Sites 7 and 8 could be considered distinct (a sub-cluster in all dendograms), followed by the sub-cluster of Sites 1 and 3 (a sub-cluster in 3 out of 5 dendograms). Coincidentally, these sub-clusters represent the clusters with the best and worst water quality, respectively.

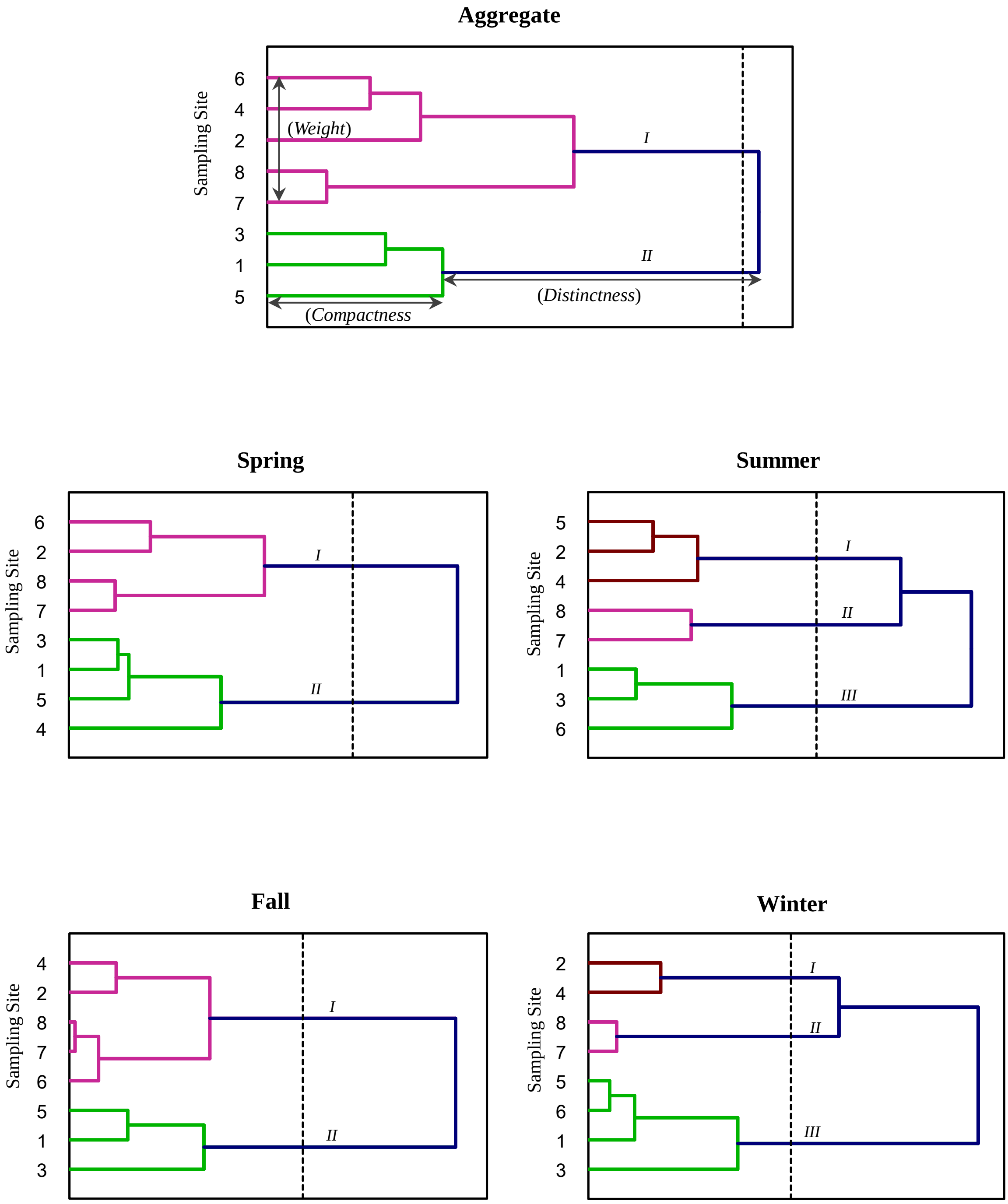



Figure 4.9: Dendograms based on hierarchical agglomerative clustering considering aggregate and seasonal data (*with truncation/broken line showing significant number of cluster at* $\alpha = 0.05$)

Table 4.13: Significant difference among sampling sites using Pairwise Mean Comparison by DMRT and grouping (*same color in brackets*) according to Cluster Analysis

| Sampling Site | Season | | | | |
|---|---|---|---|---|---|
| | Aggregate | Spring | Summer | Fall | Winter |
| 7 | a | a | a | a | a |
| 8 | a | a | a | a | a |
| 2 | b | b | ab | ab | ab |
| 4 | b | bc | ab | ab | ab |
| 6 | b | a | b | ab | ab |
| 5 | b | c | ab | ab | bc |
| 3 | c | d | b | b | cd |
| 1 | c | d | b | b | d |

*Note:* 1. Sampling site list/ranking is based on the highest mean.

2. Same letter notation means not significantly different at $\alpha$ =0.05

In Spring season, Sites 6, 2, 8 and 7 form *Cluster I* while Sites 3, 1, 5 and 4 form *Cluster II*. During this season, Sites 7 and 8 and Sites 3 and 1 have the most similar water quality within sub-clusters (similarly distinct clusters). Moreover, Site 4, together with Sites 3, 1 and 5 composed *Cluster II* which represents the cluster with lower WQI. The pairwise mean comparison analysis by DMRT shows generally the same results with that of Cluster Analysis, with Group ‘a’ and ‘b’ forming *Cluster I* and Groups ‘bc’, ‘c’ and ‘d’ forming *Cluster II*.

The Cluster Analysis of Summer season yielded three distinct clusters: *Cluster I* (Sites 5, 2 and 4) with intermediate water quality, *Cluster II* (Sites 8 and 7) with best water quality, and *Cluster III* (Sites 3, 1 and 6) with lowest water quality. Similarly with the Spring season, the results of pairwise mean comparison of Summer season generally concur with the result of cluster analysis—Group ‘a’ forming *Cluster II*, Group ‘ab’ forming *Cluster I* and Group ‘b’ forming *Cluster III*.

The Fall season consists of two clusters. Like in the aggregated data, Site 5 brought the inconsistency between cluster and pairwise mean comparison analyses. Considering the result of pairwise mean comparison, Site 5 could have been included in *Cluster I*. However, cluster analysis results showed that it is in *Cluster II* with Sites 1 and 3.

The Winter season consists of three clusters. In this season, the inconsistency between cluster and pairwise mean comparison is due to Site 6. By the pairwise mean comparison analysis, Site 6 could have been included in *Cluster I* with Sites 2 and 4.

The inconsistency findings show that Sites 5 and 6, though not having the most varied WQI values or water quality, changes similarity with other sites depending on the season.

## 4.5 Summary

This research presents the practical use and application of Water Quality Index (WQI) and some exploratory data analysis (statistical tools) to characterize the overall water quality of four rivers draining agricultural watersheds—Nara, Mima, Hiromi and Shimanto—most of which are apparently impacted by the agricultural activities along their course. The study also includes the assessment of the spatial and temporal trend and the determination of primary factors of river water quality.

The sampling site is composed of eight sampling sites, one in each of the four rivers and one in each confluence: Mima (1), Nara (2), Nara-Mima confluence (3), Hiromi (4), Mima-Hiromi confluence (5), Lower Hiromi (6), Upper Shimanto (7), and Lower Shimanto (8). The monitored parameters are a combination of physico-chemical, inorganic and bacteriological indicators: $\Delta$T, pH, Turb, TSS, DO, $BOD_5$, $NO_3$-N, $PO_4$-P and FCB. The parameters are used to compute the WQI which represents the overall water quality. The WQI was initially based from National Sanitation Foundation Index but a novel way of assigning weights to the parameters was developed from devised ranks that are based from the results of the Factor Analysis, a multivariate statistical technique. This makes the WQI conclusive and location-specific.

Based on the monitored data, Turb, TSS and DO deficit showed more erratic data, while pH data the least varied. Sampling sites 1, 2 and 3 showed higher values of water quality parameters, indicating an apparent lower water quality. Conversely, Sites 7 and 8 show the lowest values in most parameters, indicating better water quality. Except for pH and DO, the apparent general trend of the parameters is: relatively high at Site 1, decreases at Site 3 due to the influx of cleaner flow from Site 2, decreases at Site 5 due to cleaner discharge from Site 4, and further decrease in Site 6. The parameter values in Shimanto river (Sites 7 and 8) are either the same (pH, TSS, $BOD_5$, $PO_4$-P) or slightly increased (Turb, $NO_3$-N, FCB), indicating a slight undesirable effect of the flow from Hiromi river (Site 6).

The trend analysis by box-whisker plots shows an apparent seasonal difference of the water quality parameters. Turb and TSS are extremely high during spring season and decreases towards winter, indicating the apparent effect of land preparation and similar agricultural activities. FCB and $PO_4$-P are relatively high during summer and fall seasons. Conversely, DO deficit and $BOD_5$ are low during summer and fall seasons, as affected by higher water temperature. The $\Delta$T, pH and $NO_3$-N have apparently insignificant seasonal difference, indicating lesser influence on the general water quality, as also manifested in the Factor Analysis results and concurred by correlation analysis.

The results of the Factor Analysis for both aggregated data and individual sampling sites shows that the overall water quality tends to be highly influenced by FCB, $PO_4$-P, Turb, and TSS. These are also the parameters that are better correlated to WQI, based on the non-parametric Spearman correlation analysis. Hence, these parameters were given higher ranks (rank 3 or 4) and more weight (12%-18%) on the computation of the WQI. In Sites1, 3 and 5, Turb and TSS were found significantly and strongly correlated, thus, their values were averaged to prevent double weighing; and this results to two WQI equations, specific to the different sampling sites.

The correlation analysis among parameters showed high and significantly correlation between TSS:Turb in Sites 1, 3 and 5; FCB:$PO_4$-P in Sites 1, 3, 4, 5 and 6; FCB:DO in Sites 2 and 8; and Turb:pH, $PO_4$-P:DO and FCB:Turb in Sites 3, 5 and 6, respectively. And with reference to the highly correlated parameters of aggregated and seasonally-clustered data, it is appears that the parameters which correlate best with other parameters are Turb, TSS, FCB and $PO_4$-P. Further, it is observed that in river-sampling sites with better water quality (Sites 2, 4 and 8), there are very few highly-correlated parameters, suggesting a relatively independent variation among parameter values and more dependence on the river discharge and other environmental factors.

The computed WQI, representing overall water quality, shows seasonal differences. Based on WQI of aggregated data, the trend shows low water quality during spring and winter, while slightly better during summer and best during fall, as later supported by ANOVA and pairwise mean comparison analysis. This could be attributed to the fact that Spring correspond to the start of agricultural activities, especially land preparation and rice transplanting. Winter corresponds to the least-rainfall and low-discharge period and municipal effluents could have a greater effect on the water quality. Among the sampling sites, Site 1 has the lowest WQI values, indicating the ‘worst’ water quality. On the other hand, Sites 7 and 8 registered the highest WQI values, indicating the ‘best’ water quality, which is expected as the two sites are located in the Shimanto river.

The river-sampling sites with better water quality (Sites 2, 4 and 7) improved the water quality of the draining rivers at their confluence (Sites 3, 5, and 8). The water quality of Hiromi river (Site 4) slightly decreased upon the inflow of Mima river (Site 3). Hiromi river with its water quality further decreased at Site 6, slightly affected (decreased) the water quality of Shimanto river (Site 7 → Site 8).

The Cluster Analysis showed a different clustering of sampling sites when analysis is done on aggregated and seasonal data, a finding concurred by pairwise mean comparison analysis. Cluster Analysis conducted on aggregated data, as well as on Spring and Fall seasons results to two significant clusters; while three clusters for Summer and Winter seasons. Considering all results, it is apparent that only the clusters of Sites 7 and 8 and Sites 1 and 3 are significantly distinct clusters—representing the clusters with the best and worst water quality, respectively. The other sites are either in the same or in different clusters, depending on the season.

# CHAPTER V

## CONCLUSION and RECOMMENDATION

The monitoring and analysis of water quality is of paramount importance in the evaluation of the environmental status of water bodies. Information on water quality and pollution sources is important for the implementation of sustainable water-use management.

In rural areas, agricultural activities often influence the river water quality, whether it is pollutants from point and non-point sources. And one of the major pollutants in rivers which can be attributed to agricultural cultivation and related activities is suspended sediment, considered the most abundant, most visible and a major factor of the physical state of water bodies. In relation to this, a study was conducted to investigate the suspended sediment transport of relatively small rivers, apparently impacted by agricultural activities. Suspended sediment is just one of the many factors affecting the overall water quality of the rivers, hence, a general water quality characterization was also done to include other important water quality characteristics necessary to describe the present state of studied rivers.

In this study, being a core part of the sediment transport analysis, the suspended sediment load is estimated using suspended sediment rating curves established using discharge-suspended sediment discharge correlation on aggregated or seasonally-clustered data. Data stratification was found necessary during analysis due to the occurrence of nil sediment values, making the power function model adaptable to the monitored data. The study further delves on the assessment of using linear (LLS) and non-linear least squares (NLLS) methods during regression analysis and their effect on the estimated load values (SL).

The results of regression shows that power function developed by NLLS produces significantly better and more efficient suspended sediment rating curves than those developed by LLS, and is apparently more appropriate in small rivers with wide range of discharge and suspended sediment values. Specifically, the curves developed through LLS method tended to be biased to the smaller values, hence, high values especially during storm events are not well-presented in the curve, resulting to highly underestimated sediment load values. For any type of data, NLLS tend to give a better annual SL estimates. Seasonally-clustering the data also results to producing better suspended sediment rating curves, although the difference between with and without seasonal clustering is not significant.

The temporal variability analysis, based on statistical and physical relations, shows that suspended sediment load in the catchment follows a clear cyclical seasonal pattern, that is, increasing from spring to summer season and decreasing into fall and winter seasons; and a rather erratic and multi-nodal monthly distribution. The temporal distribution and variability of the sediment load appears to be mainly related to two major factors: rainfall and agricultural activities. The agricultural activities apparently affects the suspended sediment load during Spring, the agricultural activities and rainfall during Summer, the rainfall during Fall, and the absence of both during Winter. Moreover, suspended sediment load was found higher during rice transplanting season and the activities was found to have contributed considerable amount of suspended sediment during the period, supporting the conjecture that sediments come from sources other than natural soil erosion.

On the other hand, the general water quality characterization focused on the importance of water quality index (WQI) as a key element in the assessment of river water quality; and the applicability and practical use of some exploratory data analyses in the determination and interpretation of the temporal and spatial variation of water quality. The evaluation by exploratory statistical analysis includes correlation and trend analysis, ANOVA with pairwise means comparison, and two multivariate statistical analyses—Factor Analysis to determine the more important water quality factors and Cluster Analysis to determine the variation of water quality level among sampling sites.

Characterization analyses results showed that WQI and individual parameters have apparent seasonal pattern and differences. The analyses showed better and more interpretable results when conducted for each season and in each sampling site, rather than on aggregated data, indicating seasonality and location-specificity of the water quality. Based on the factor analysis, the parameters that highly influence pollution in the rivers are Fecal Coliform Bacteria, $PO_4$-P, Turbidity, Total Suspended Solids; and are also the factors that correlates with the WQI better. Cluster Analysis, coupled with pairwise mean comparison analysis, was able to determine the spatial variation of water quality and had somehow achieved a meaningful classification of river sampling sites based on its water quality index.

Primarily, the identified effect of agricultural cultivation and related activities on the rivers involves general water quality deterioration. And since water quality is vital for the success of agriculture, proper agriculture management practices are necessary to meet water quality standards and provide for ecosystem health. Hence, cooperation of the agricultural sector and domestic water users, as should be encouraged and regulated by government policies, is necessary to provide adequate water resources and maintain good water quality.

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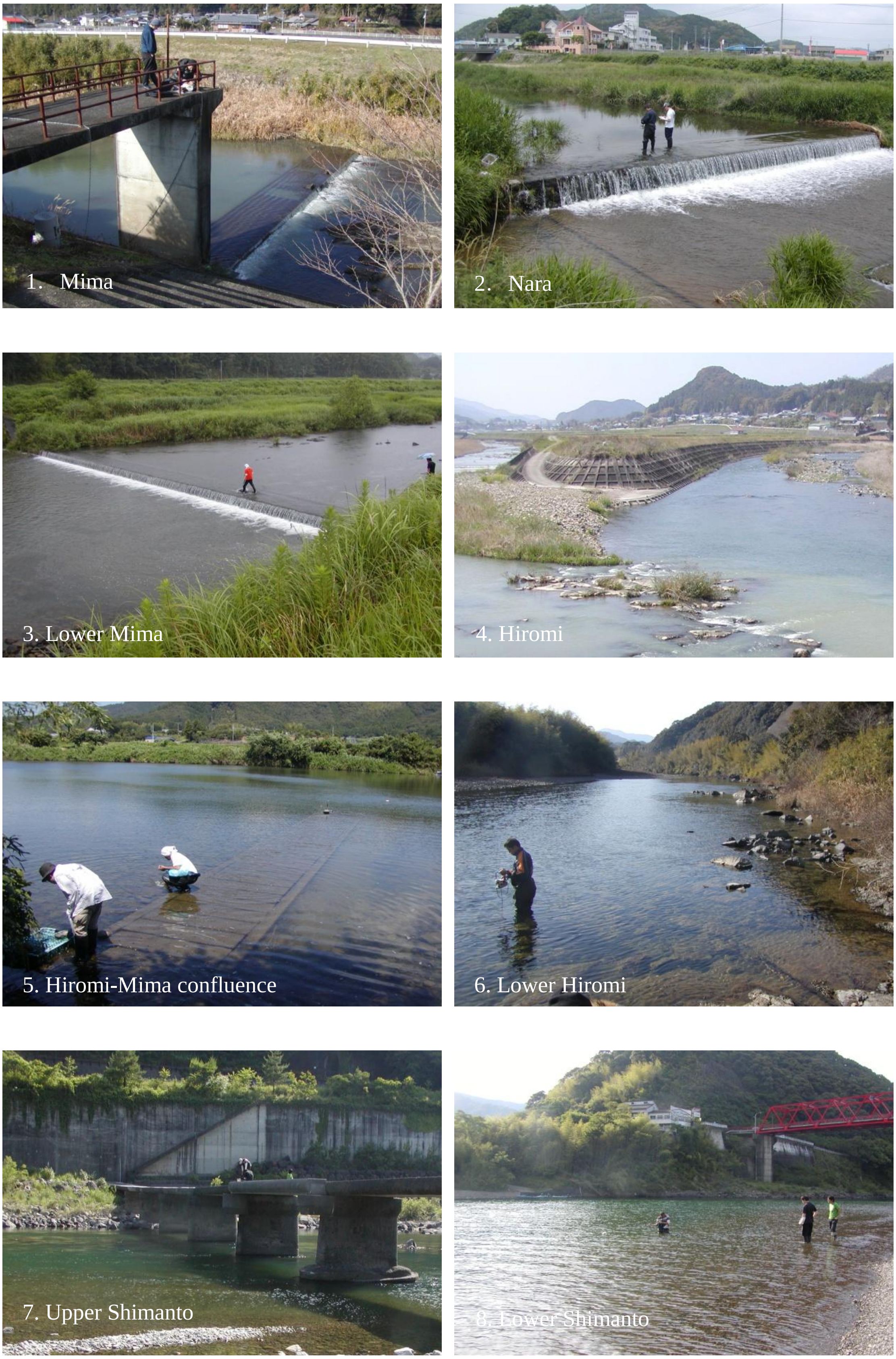
# APPENDICES

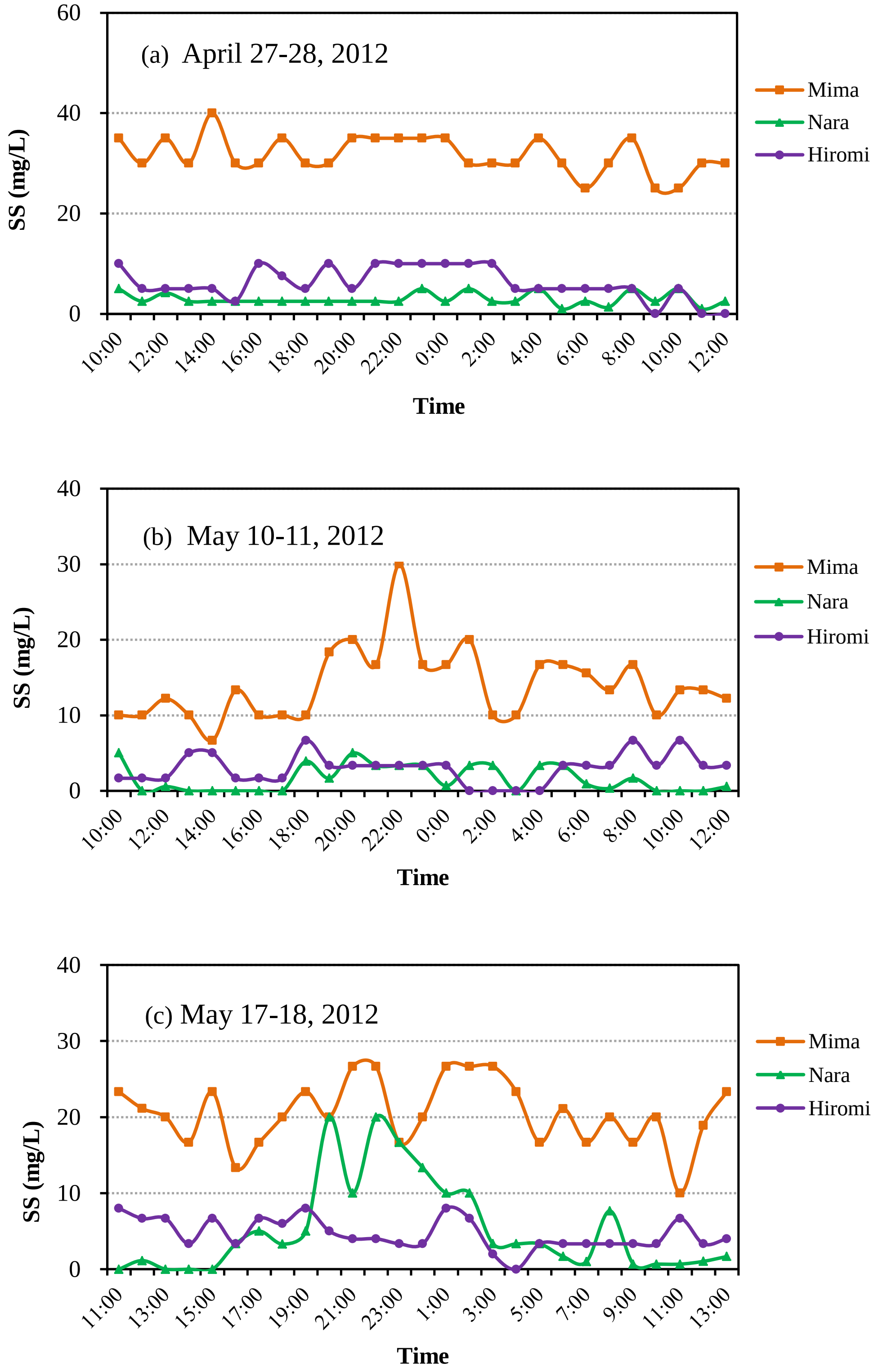



Appendix Figure 1: Observation and sampling sites

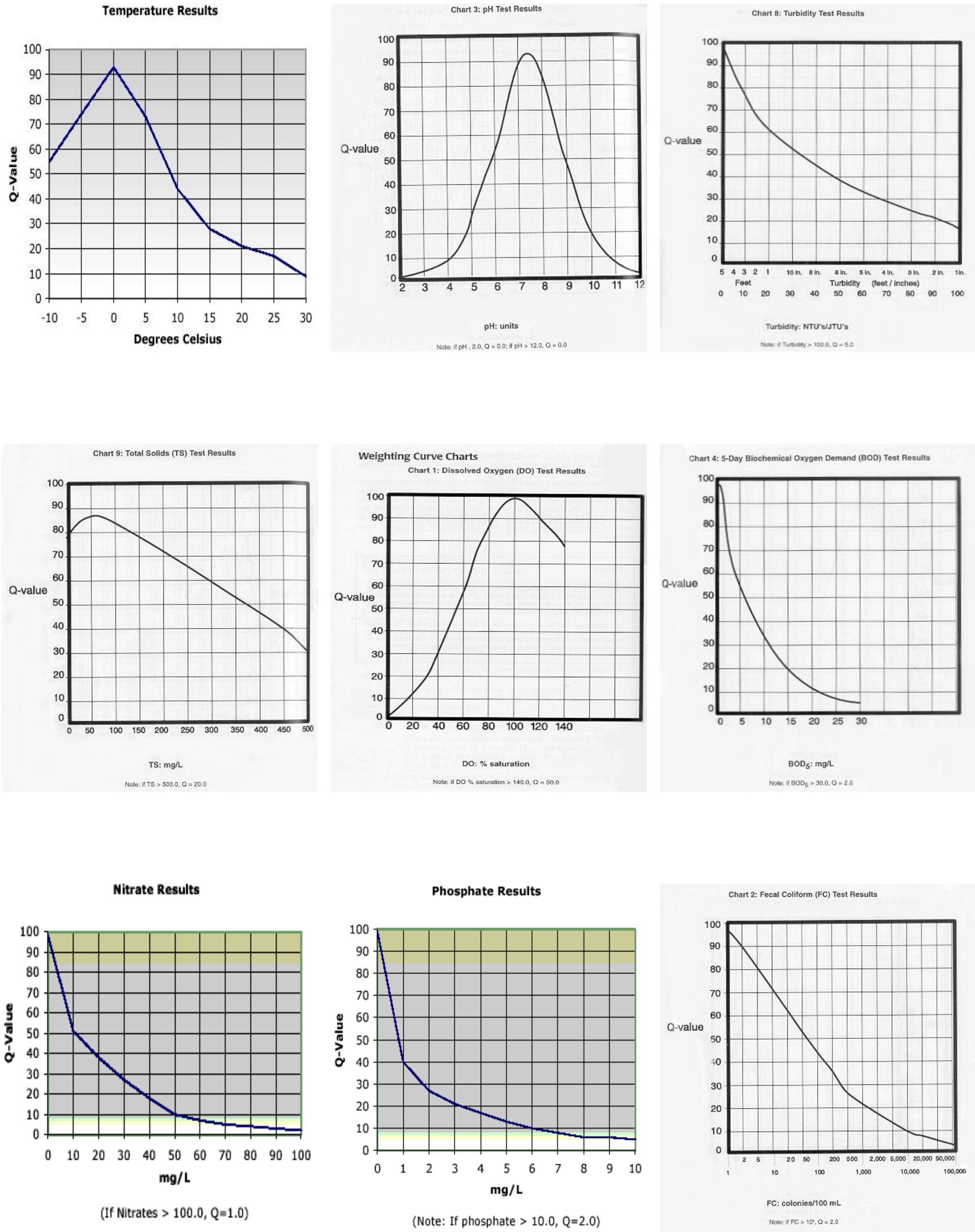
Appendix Figure 2: Mima River draining turbid and highly sedimented water into Hiromi River

Appendix Figure 3: Hiromi River draining turbid and highly sedimented water into Shimanto River

Appendix Figure 4: Drainage water from some rice paddy fields




Appendix Figure 5: 24-hour monitoring of suspended sediment

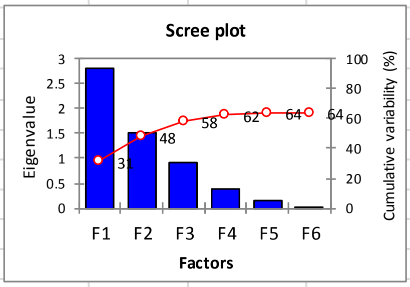



Appendix Figure 6: Q-curves of the different water quality parameters

* AGGREGATE

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.809 | 1.504 | 0.922 | 0.378 | 0.141 | 0.008 |
| Variability | 31.206 | 16.709 | 10.249 | 4.204 | 1.567 | 0.089 |
| Cumulative | 31.206 | 47.915 | 58.164 | 62.368 | 63.935 | 64.025 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | -0.009 | 0.059 | 0.117 | -0.391 | -0.504 | -0.019 |
| pH | -0.171 | 0.475 | -0.392 | -0.405 | 0.375 | -0.134 |
| Turb | 0.450 | -0.069 | -0.186 | 0.203 | -0.246 | -0.677 |
| TSS | 0.397 | -0.073 | -0.681 | 0.160 | 0.018 | 0.522 |
| DO Def. | -0.234 | -0.544 | -0.099 | 0.335 | 0.335 | -0.205 |
| BOD5b | -0.163 | -0.239 | -0.487 | -0.290 | -0.405 | -0.206 |
| NO3-N | 0.247 | -0.611 | 0.155 | -0.595 | 0.173 | 0.161 |
| PO4-P | 0.461 | 0.111 | 0.046 | -0.232 | 0.461 | -0.319 |
| FCB | 0.506 | 0.148 | 0.249 | 0.114 | -0.159 | 0.198 |

Factor pattern:

| | F1 | F2 | F3 | F4 | l commur | l commun | cific variance |
|---|---|---|---|---|---|---|---|
| ΔT | -0.016 | 0.073 | 0.112 | **-0.240** | 0.068 | 0.076 | 0.924 |
| pH | -0.286 | **0.583** | -0.377 | -0.249 | 0.466 | 0.625 | 0.375 |
| Turb | **0.754** | -0.084 | -0.178 | 0.125 | 0.571 | 0.623 | 0.377 |
| TSS | **0.665** | -0.089 | -0.654 | 0.099 | 0.509 | 0.887 | 0.113 |
| DO Def. | -0.393 | **-0.667** | -0.095 | 0.206 | 0.477 | 0.651 | 0.349 |
| BOD5b | -0.274 | -0.293 | **-0.468** | -0.178 | 0.330 | 0.411 | 0.589 |
| NO3-N | 0.414 | **-0.749** | 0.148 | -0.366 | 0.449 | 0.889 | 0.111 |
| PO4-P | **0.773** | 0.136 | 0.044 | -0.143 | 0.593 | 0.638 | 0.362 |
| FCB | **0.848** | 0.181 | 0.239 | 0.070 | 0.658 | 0.813 | 0.187 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 | F4 |
|---|---|---|---|---|
| ΔT | 0.038 | 0.047 | 0.035 | -0.252 |
| pH | 0.172 | 0.521 | -0.006 | -0.466 |
| Turb | 0.727 | -0.235 | -0.663 | 0.069 |
| TSS | 0.800 | -0.156 | -0.837 | 0.120 |
| DO Def. | -0.289 | -0.641 | -0.041 | 0.286 |
| BOD5b | -0.088 | -0.149 | -0.290 | -0.290 |
| NO3-N | 0.497 | -0.746 | 0.050 | -0.628 |
| PO4-P | 0.691 | 0.147 | -0.162 | -0.258 |
| FCB | 0.758 | 0.243 | -0.029 | -0.398 |

Factor pattern and correlation after Varimax rotatio

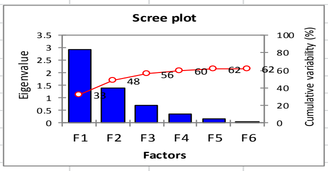
| | D1 | D1 |
|---|---|---|
| ΔT | **-0.016** | 0.034 |
| pH | **-0.286** | -0.325 |
| Turb | **0.754** | 0.763 |
| TSS | **0.665** | 0.846 |
| DO Def. | **-0.393** | -0.317 |
| BOD5b | **-0.274** | -0.243 |
| NO3-N | **0.414** | 0.468 |
| PO4-P | **0.773** | 0.694 |
| FCB | **0.848** | 0.815 |

Appendix 7: Factor analysis results for aggregated data (eigenvalues, eigenvectors, factor pattern and scree plot)

**1. MIMA**

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.940 | 1.413 | 0.694 | 0.346 | 0.166 | 0.015 |
| Variability | 32.669 | 15.700 | 7.709 | 3.840 | 1.844 | 0.171 |
| Cumulativ | 32.669 | 48.368 | 56.077 | 59.917 | 61.761 | 61.932 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | −0.138 | 0.334 | 0.067 | −0.276 | −0.597 | 0.009 |
| pH | −0.150 | −0.637 | −0.566 | −0.086 | −0.259 | 0.267 |
| Turb | 0.382 | 0.356 | −0.351 | −0.017 | 0.094 | 0.717 |
| TSS | 0.394 | 0.241 | −0.535 | −0.159 | 0.278 | −0.512 |
| DO Def. | −0.283 | 0.290 | −0.171 | 0.494 | −0.083 | 0.106 |
| BOD5b | −0.315 | 0.230 | −0.325 | −0.463 | −0.257 | −0.189 |
| NO3−N | −0.020 | 0.271 | −0.158 | 0.531 | −0.338 | −0.133 |
| PO4−P | 0.458 | −0.295 | −0.100 | 0.312 | −0.403 | −0.271 |
| FCB | 0.517 | 0.028 | 0.311 | −0.231 | −0.374 | 0.119 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific varia | ecific variance |
|---|---|---|---|---|---|---|---|
| ΔT | −0.236 | **0.397** | 0.056 | 0.270 | 0.217 | 0.783 | 0.924 |
| pH | −0.257 | **−0.757** | −0.471 | 0.564 | 0.861 | 0.139 | 0.375 |
| Turb | **0.655** | 0.424 | −0.292 | 0.584 | 0.694 | 0.306 | 0.377 |
| TSS | **0.676** | 0.286 | −0.445 | 0.591 | 0.737 | 0.263 | 0.113 |
| DO Def. | **−0.486** | 0.344 | −0.143 | 0.394 | 0.375 | 0.625 | 0.349 |
| BOD5b | **−0.540** | 0.273 | −0.271 | 0.479 | 0.439 | 0.561 | 0.589 |
| NO3−N | −0.035 | **0.322** | −0.131 | 0.266 | 0.122 | 0.878 | 0.111 |
| PO4−P | **0.785** | −0.351 | −0.084 | 0.765 | 0.747 | 0.253 | 0.362 |
| FCB | **0.887** | 0.033 | 0.259 | 0.780 | 0.856 | 0.144 | 0.187 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | −0.060 | 0.104 | −0.071 |
| pH | −0.043 | −0.653 | −0.559 |
| Turb | 0.144 | 0.266 | −0.318 |
| TSS | 0.212 | 0.152 | −0.556 |
| DO Def. | −0.044 | 0.120 | −0.100 |
| BOD5b | −0.089 | 0.175 | −0.077 |
| NO3−N | −0.013 | 0.064 | −0.047 |
| PO4−P | 0.241 | −0.120 | −0.045 |
| FCB | 0.453 | −0.172 | 0.424 |

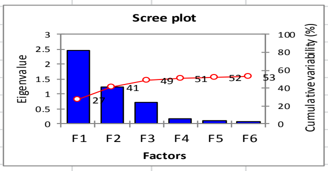
Factor pattern and correlation after Varimax rotation:

| | D1 | D1 |
|---|---|---|
| ΔT | **−0.236** | −0.085 |
| pH | **−0.257** | −0.254 |
| Turb | **0.655** | 0.628 |
| TSS | **0.676** | 0.754 |
| DO Def. | **−0.486** | −0.458 |
| BOD5b | **−0.540** | −0.544 |
| NO3−N | **−0.035** | 0.027 |
| PO4−P | **0.785** | 0.830 |
| FCB | **0.887** | 0.912 |

**2. NARA**

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalu | 2.466 | 1.227 | 0.731 | 0.176 | 0.115 | 0.071 |
| Variability | 27.404 | 13.628 | 8.118 | 1.952 | 1.282 | 0.787 |
| Cumulati | 27.404 | 41.032 | 49.150 | 51.102 | 52.384 | 53.171 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | −0.305 | 0.201 | −0.079 | −0.108 | 0.516 | 0.154 |
| pH | 0.130 | 0.787 | −0.380 | 0.107 | −0.144 | −0.310 |
| Turb | −0.276 | −0.258 | −0.252 | −0.218 | −0.510 | 0.185 |
| TSS | −0.036 | 0.245 | 0.154 | −0.544 | −0.246 | 0.396 |
| DO Def. | 0.545 | 0.067 | 0.355 | 0.053 | −0.440 | −0.051 |
| BOD5b | 0.453 | −0.238 | −0.765 | −0.042 | 0.046 | 0.254 |
| NO3−N | 0.064 | −0.135 | 0.085 | 0.688 | −0.003 | 0.268 |
| PO4−P | −0.306 | 0.327 | −0.049 | 0.365 | −0.250 | 0.565 |
| FCB | −0.462 | −0.165 | −0.204 | 0.150 | −0.366 | −0.480 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific variance |
|---|---|---|---|---|---|---|
| ΔT | **−0.478** | 0.223 | −0.068 | 0.291 | 0.283 | 0.717 |
| pH | 0.205 | **0.871** | −0.325 | 0.313 | 0.907 | 0.093 |
| Turb | **−0.433** | −0.286 | −0.215 | 0.298 | 0.316 | 0.684 |
| TSS | −0.057 | **0.272** | 0.131 | 0.122 | 0.094 | 0.906 |
| DO Def. | **0.855** | 0.074 | 0.303 | 0.588 | 0.829 | 0.171 |
| BOD5b | **0.710** | −0.263 | −0.653 | 0.367 | **1.000** | **0.000** |
| NO3−N | 0.101 | **−0.149** | 0.073 | 0.096 | 0.038 | 0.962 |
| PO4−P | **−0.481** | 0.362 | −0.042 | 0.381 | 0.364 | 0.636 |
| FCB | **−0.725** | −0.183 | −0.174 | 0.520 | 0.590 | 0.410 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | −0.422 | 0.297 | −0.006 |
| pH | 0.273 | 0.895 | −0.394 |
| Turb | −0.185 | −0.247 | −0.170 |
| TSS | 0.000 | 0.141 | 0.064 |
| DO Def. | 0.853 | 0.151 | 0.367 |
| BOD5b | 0.679 | −0.201 | −0.747 |
| NO3−N | 0.119 | −0.193 | 0.086 |
| PO4−P | −0.415 | 0.353 | −0.056 |
| FCB | −0.709 | −0.253 | −0.239 |

Factor pattern and correlation after Varimax rotation:

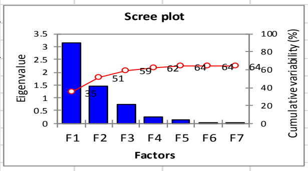
| | D1 | D1 |
|---|---|---|
| ΔT | **0.478** | 0.422 |
| pH | **−0.205** | −0.273 |
| Turb | **0.433** | 0.185 |
| TSS | **0.057** | 0.000 |
| DO Def. | **−0.855** | −0.853 |
| BOD5b | **−0.710** | −0.679 |
| NO3−N | **−0.101** | −0.119 |
| PO4−P | **0.481** | 0.415 |
| FCB | **0.725** | 0.709 |

Appendix 8: Factor analysis results for Mima and Nara (eigenvalues, eigenvectors, factor pattern and scree plot)

### 3. LOWER MIMA

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 |
|---|---|---|---|---|---|---|---|
| Eigenvalue | 3.127 | 1.467 | 0.744 | 0.259 | 0.134 | 0.037 | 0.011 |
| Variability | 34.740 | 16.296 | 8.262 | 2.881 | 1.490 | 0.409 | 0.122 |
| Cumulativ | 34.740 | 51.036 | 59.298 | 62.179 | 63.669 | 64.078 | 64.200 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 |
|---|---|---|---|---|---|---|---|
| ΔT | 0.296 | 0.146 | −0.575 | −0.156 | 0.429 | 0.398 | −0.056 |
| pH | −0.241 | 0.447 | −0.154 | −0.580 | 0.018 | −0.083 | −0.124 |
| Turb | 0.448 | −0.344 | −0.173 | 0.100 | 0.304 | −0.596 | −0.275 |
| TSS | 0.420 | −0.177 | −0.400 | −0.240 | −0.502 | 0.130 | 0.221 |
| DO Def. | −0.184 | −0.423 | 0.130 | −0.239 | 0.229 | 0.379 | −0.602 |
| BOD5b | −0.305 | −0.206 | −0.339 | −0.107 | −0.534 | −0.242 | −0.399 |
| NO3−N | 0.093 | −0.531 | 0.306 | −0.450 | −0.021 | 0.160 | 0.366 |
| PO4−P | 0.362 | 0.280 | 0.386 | −0.497 | 0.001 | −0.314 | −0.153 |
| FCB | 0.459 | 0.218 | 0.285 | 0.233 | −0.364 | 0.369 | −0.422 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific variance |
|---|---|---|---|---|---|---|
| ΔT | **0.523** | 0.177 | −0.496 | 0.477 | 0.550 | 0.450 |
| pH | −0.426 | **0.541** | −0.133 | 0.668 | 0.492 | 0.508 |
| Turb | **0.792** | −0.417 | −0.149 | 0.733 | 0.823 | 0.177 |
| TSS | **0.743** | −0.214 | −0.345 | 0.680 | 0.717 | 0.283 |
| DO Def. | −0.326 | **−0.512** | 0.112 | 0.341 | 0.381 | 0.619 |
| BOD5b | **−0.539** | −0.249 | −0.292 | 0.430 | 0.438 | 0.562 |
| NO3−N | 0.164 | **−0.644** | 0.264 | 0.485 | 0.510 | 0.490 |
| PO4−P | **0.640** | 0.339 | 0.333 | 0.703 | 0.635 | 0.365 |
| FCB | **0.812** | 0.264 | 0.246 | 0.745 | 0.790 | 0.210 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | 0.320 | 0.389 | −0.560 |
| pH | −0.318 | 0.502 | −0.259 |
| Turb | 0.784 | −0.562 | −0.213 |
| TSS | 0.852 | −0.284 | −0.309 |
| DO Def. | −0.261 | −0.602 | 0.151 |
| BOD5b | −0.483 | −0.333 | −0.412 |
| NO3−N | 0.218 | −0.690 | 0.447 |
| PO4−P | 0.687 | 0.318 | 0.379 |
| FCB | 0.818 | 0.265 | 0.366 |

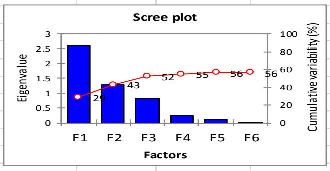
Factor pattern and correlation after Varimax rotation:

| | D1 | D1 |
|---|---|---|
| ΔT | **0.523** | 0.320 |
| pH | **−0.426** | −0.318 |
| Turb | **0.792** | 0.784 |
| TSS | **0.743** | 0.852 |
| DO Def. | **−0.326** | −0.261 |
| BOD5b | **−0.539** | −0.483 |
| NO3−N | **0.164** | 0.218 |
| PO4−P | **0.640** | 0.687 |
| FCB | **0.812** | 0.818 |

### 4. HIROMI

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.608 | 1.288 | 0.818 | 0.249 | 0.106 | 0.005 |
| Variability | 28.981 | 14.316 | 9.086 | 2.769 | 1.183 | 0.061 |
| Cumulativ | 28.981 | 43.297 | 52.384 | 55.153 | 56.336 | 56.396 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | 0.138 | −0.195 | −0.219 | 0.384 | 0.439 | 0.496 |
| pH | 0.045 | −0.740 | 0.109 | −0.331 | 0.311 | 0.120 |
| Turb | 0.411 | 0.326 | −0.670 | −0.306 | 0.131 | 0.022 |
| TSS | 0.162 | −0.289 | −0.395 | 0.298 | −0.119 | −0.466 |
| DO Def. | −0.458 | 0.297 | −0.152 | −0.176 | 0.485 | 0.195 |
| BOD5b | −0.287 | −0.193 | −0.393 | 0.440 | −0.318 | 0.312 |
| NO3−N | −0.245 | 0.239 | 0.176 | 0.476 | 0.281 | −0.208 |
| PO4−P | 0.446 | 0.031 | 0.166 | 0.296 | 0.457 | −0.283 |
| FCB | 0.482 | 0.204 | 0.315 | 0.145 | −0.235 | 0.512 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific variance |
|---|---|---|---|---|---|---|
| ΔT | **0.223** | −0.221 | −0.198 | 0.186 | 0.138 | 0.862 |
| pH | 0.073 | **−0.840** | 0.098 | 0.514 | 0.720 | 0.280 |
| Turb | **0.664** | 0.371 | −0.606 | 0.523 | 0.945 | 0.055 |
| TSS | 0.262 | −0.328 | **−0.357** | 0.280 | 0.304 | 0.696 |
| DO Def. | **−0.740** | 0.337 | −0.137 | 0.570 | 0.680 | 0.320 |
| BOD5b | **−0.464** | −0.219 | −0.355 | 0.363 | 0.389 | 0.611 |
| NO3−N | **−0.396** | 0.272 | 0.159 | 0.349 | 0.256 | 0.744 |
| PO4−P | **0.720** | 0.035 | 0.150 | 0.485 | 0.542 | 0.458 |
| FCB | **0.778** | 0.232 | 0.285 | 0.582 | 0.741 | 0.259 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | 0.182 | −0.248 | −0.178 |
| pH | 0.090 | −0.922 | 0.093 |
| Turb | 0.637 | 0.382 | −0.739 |
| TSS | 0.436 | −0.184 | −0.398 |
| DO Def. | −0.721 | 0.382 | −0.184 |
| BOD5b | −0.426 | −0.203 | −0.312 |
| NO3−N | −0.342 | 0.387 | 0.121 |
| PO4−P | 0.721 | −0.023 | 0.183 |
| FCB | 0.750 | 0.223 | 0.389 |

Factor pattern and correlation after Varimax rotation:

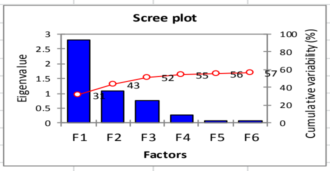
| | D1 | D1 |
|---|---|---|
| ΔT | **0.223** | 0.182 |
| pH | **0.073** | 0.090 |
| Turb | **0.664** | 0.637 |
| TSS | **0.262** | 0.436 |
| DO Def. | **−0.740** | −0.721 |
| BOD5b | **−0.464** | −0.426 |
| NO3−N | **−0.396** | −0.342 |
| PO4−P | **0.720** | 0.721 |
| FCB | **0.778** | 0.750 |

Appendix 9: Factor analysis results for Lower Mima and Hiromi (eigenvalues, eigenvectors, factor pattern and scree plot)

**5. HIROMI-MIMA Confluence**

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.813 | 1.077 | 0.763 | 0.266 | 0.091 | 0.083 |
| Variability | 31.261 | 11.964 | 8.483 | 2.955 | 1.009 | 0.927 |
| Cumulativ | 31.261 | 43.225 | 51.708 | 54.662 | 55.672 | 56.598 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | -0.085 | -0.376 | 0.636 | -0.003 | 0.416 | 0.262 |
| pH | -0.100 | 0.462 | -0.267 | -0.356 | 0.435 | -0.006 |
| Turb | 0.436 | -0.531 | -0.395 | 0.027 | -0.129 | 0.322 |
| TSS | 0.257 | -0.241 | -0.430 | -0.043 | 0.536 | -0.156 |
| DO Def. | -0.397 | -0.192 | -0.225 | 0.299 | 0.075 | -0.519 |
| BOD5b | -0.334 | -0.250 | -0.035 | -0.515 | 0.279 | 0.148 |
| NO3-N | -0.101 | -0.418 | 0.111 | -0.403 | -0.260 | -0.546 |
| PO4-P | 0.429 | 0.158 | 0.133 | -0.556 | -0.221 | -0.155 |
| FCB | 0.513 | 0.073 | 0.318 | 0.210 | 0.366 | -0.436 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific variance |
|---|---|---|---|---|---|---|
| ΔT | -0.142 | -0.391 | **0.556** | 0.242 | 0.482 | 0.518 |
| pH | -0.167 | **0.480** | -0.234 | 0.318 | 0.312 | 0.688 |
| Turb | **0.731** | -0.551 | -0.345 | 0.539 | 0.956 | 0.044 |
| TSS | **0.432** | -0.250 | -0.376 | 0.408 | 0.390 | 0.610 |
| DO Def. | **-0.665** | -0.200 | -0.196 | 0.495 | 0.521 | 0.479 |
| BOD5b | **-0.560** | -0.259 | -0.031 | 0.425 | 0.382 | 0.618 |
| NO3-N | -0.170 | **-0.434** | 0.097 | 0.254 | 0.227 | 0.773 |
| PO4-P | **0.720** | 0.164 | 0.116 | 0.622 | 0.559 | 0.441 |
| FCB | **0.861** | 0.076 | 0.278 | 0.656 | 0.824 | 0.176 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | -0.148 | -0.498 | 0.570 |
| pH | -0.066 | 0.478 | -0.277 |
| Turb | 0.694 | -0.685 | -0.481 |
| TSS | 0.689 | -0.326 | -0.415 |
| DO Def. | -0.630 | -0.257 | -0.182 |
| BOD5b | -0.439 | -0.432 | -0.195 |
| NO3-N | -0.057 | -0.407 | 0.102 |
| PO4-P | 0.723 | 0.184 | 0.127 |
| FCB | 0.871 | 0.156 | 0.321 |

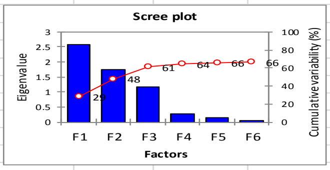
Factor pattern and correlation after Varimax rotation:

| | D1 | D1 |
|---|---|---|
| ΔT | **-0.142** | -0.148 |
| pH | **-0.167** | -0.066 |
| Turb | **0.731** | 0.694 |
| TSS | **0.432** | 0.689 |
| DO Def. | **-0.665** | -0.630 |
| BOD5b | **-0.560** | -0.439 |
| NO3-N | **-0.170** | -0.057 |
| PO4-P | **0.720** | 0.723 |
| FCB | **0.861** | 0.871 |

**6. LOWER HIROMI**

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.576 | 1.752 | 1.181 | 0.283 | 0.142 | 0.045 |
| Variability | 28.627 | 19.468 | 13.125 | 3.147 | 1.575 | 0.500 |
| Cumulativ | 28.627 | 48.096 | 61.220 | 64.367 | 65.943 | 66.443 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | 0.264 | -0.270 | -0.288 | -0.509 | 0.096 | -0.246 |
| pH | 0.119 | -0.514 | 0.070 | 0.243 | 0.523 | 0.330 |
| Turb | 0.331 | 0.368 | 0.101 | -0.429 | 0.243 | 0.121 |
| TSS | 0.094 | 0.039 | 0.913 | -0.016 | 0.105 | -0.266 |
| DO Def. | -0.451 | 0.361 | -0.086 | 0.376 | 0.141 | -0.085 |
| BOD5b | -0.358 | -0.173 | 0.188 | -0.271 | -0.014 | 0.705 |
| NO3-N | -0.225 | 0.496 | -0.075 | -0.321 | 0.401 | 0.145 |
| PO4-P | 0.432 | 0.190 | -0.136 | 0.388 | 0.474 | 0.085 |
| FCB | 0.477 | 0.288 | 0.041 | 0.171 | -0.491 | 0.462 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific variance |
|---|---|---|---|---|---|---|
| ΔT | **0.424** | -0.358 | -0.313 | 0.560 | 0.406 | 0.594 |
| pH | 0.192 | **-0.680** | 0.076 | 0.550 | 0.505 | 0.495 |
| Turb | **0.532** | 0.488 | 0.110 | 0.563 | 0.533 | 0.467 |
| TSS | 0.150 | 0.051 | **0.987** | 0.397 | **1.000** | **0.000** |
| DO Def. | **-0.724** | 0.478 | -0.093 | 0.673 | 0.762 | 0.238 |
| BOD5b | **-0.575** | -0.229 | 0.205 | 0.410 | 0.425 | 0.575 |
| NO3-N | -0.361 | **0.657** | -0.081 | 0.542 | 0.569 | 0.431 |
| PO4-P | **0.694** | 0.251 | -0.148 | 0.593 | 0.566 | 0.434 |
| FCB | **0.766** | 0.381 | 0.044 | 0.709 | 0.734 | 0.266 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | 0.346 | -0.428 | -0.315 |
| pH | 0.164 | -0.715 | -0.233 |
| Turb | 0.418 | 0.634 | 0.676 |
| TSS | 0.446 | 0.395 | 0.986 |
| DO Def. | -0.758 | 0.505 | -0.098 |
| BOD5b | -0.559 | -0.269 | -0.170 |
| NO3-N | -0.289 | 0.694 | -0.054 |
| PO4-P | 0.506 | 0.167 | 0.085 |
| FCB | 0.789 | 0.476 | 0.512 |

Factor pattern and correlation after Varimax rotation:

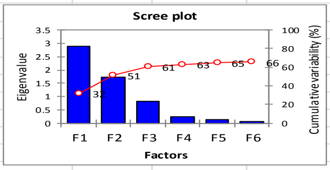
| | D1 | D1 |
|---|---|---|
| ΔT | **0.424** | 0.346 |
| pH | **0.192** | 0.164 |
| Turb | **0.532** | 0.418 |
| TSS | **0.150** | 0.446 |
| DO Def. | **-0.724** | -0.758 |
| BOD5b | **-0.575** | -0.559 |
| NO3-N | **-0.361** | -0.289 |
| PO4-P | **0.694** | 0.506 |
| FCB | **0.766** | 0.789 |

Appendix 10: Factor analysis results for Hiromi-Mima confluence and Lower Hiromi (eigenvalues, eigenvectors, factor pattern and scree plot)

## 7. UPPER SHIMANTO

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.892 | 1.730 | 0.824 | 0.252 | 0.152 | 0.062 |
| Variability | 32.133 | 19.224 | 9.154 | 2.795 | 1.686 | 0.693 |
| Cumulative | 32.133 | 51.358 | 60.512 | 63.307 | 64.993 | 65.686 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | −0.204 | −0.343 | −0.163 | −0.478 | 0.111 | −0.486 |
| pH | −0.071 | −0.631 | 0.621 | −0.009 | 0.009 | 0.165 |
| Turb | −0.431 | 0.349 | −0.006 | −0.069 | 0.592 | 0.057 |
| TSS | 0.318 | −0.122 | −0.093 | 0.665 | 0.010 | −0.180 |
| DO Def. | 0.460 | 0.206 | 0.172 | 0.051 | 0.481 | −0.284 |
| BOD5b | 0.396 | 0.013 | 0.129 | −0.299 | 0.292 | 0.620 |
| NO3−N | −0.056 | 0.533 | 0.636 | −0.100 | −0.392 | −0.200 |
| PO4−P | −0.317 | −0.121 | 0.338 | 0.353 | 0.398 | −0.159 |
| FCB | −0.441 | 0.078 | −0.116 | 0.313 | −0.095 | 0.413 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific variance |
|---|---|---|---|---|---|---|
| ΔT | −0.347 | **−0.452** | −0.148 | 0.428 | 0.346 | 0.654 |
| pH | −0.120 | **−0.821** | 0.558 | 0.546 | **1.000** | **0.000** |
| Turb | **−0.732** | 0.460 | −0.005 | 0.685 | 0.747 | 0.253 |
| TSS | **0.541** | −0.160 | −0.085 | 0.512 | 0.326 | 0.674 |
| DO Def. | **0.783** | 0.271 | 0.156 | 0.636 | 0.711 | 0.289 |
| BOD5b | **0.673** | 0.018 | 0.117 | 0.509 | 0.467 | 0.533 |
| NO3−N | −0.096 | **0.701** | 0.578 | 0.467 | 0.834 | 0.166 |
| PO4−P | **−0.539** | −0.159 | 0.307 | 0.504 | 0.410 | 0.590 |
| FCB | **−0.750** | 0.103 | −0.106 | 0.539 | 0.584 | 0.416 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | −0.301 | −0.383 | −0.167 |
| pH | −0.079 | −0.854 | 0.565 |
| Turb | −0.614 | 0.455 | −0.043 |
| TSS | −0.449 | 0.261 | −0.080 |
| DO Def. | 0.778 | 0.255 | 0.151 |
| BOD5b | 0.674 | −0.043 | 0.085 |
| NO3−N | −0.039 | 0.695 | 0.538 |
| PO4−P | −0.519 | −0.106 | 0.402 |
| FCB | −0.699 | 0.180 | −0.032 |

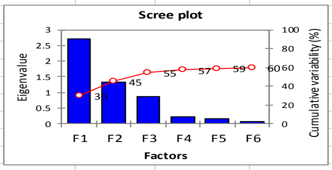
Factor pattern and correlation after Varimax rotation:

| | D1 | D1 |
|---|---|---|
| ΔT | **0.347** | 0.301 |
| pH | **0.120** | 0.079 |
| Turb | **0.732** | 0.614 |
| TSS | **−0.541** | 0.449 |
| DO Def. | **−0.783** | −0.778 |
| BOD5b | **−0.673** | −0.674 |
| NO3−N | **0.096** | 0.039 |
| PO4−P | **0.539** | 0.519 |
| FCB | **0.750** | 0.699 |

## 8. LOWER SHIMANTO

Eigenvalues:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.724 | 1.335 | 0.866 | 0.238 | 0.158 | 0.086 |
| Variability | 30.268 | 14.835 | 9.627 | 2.649 | 1.761 | 0.954 |
| Cumulative | 30.268 | 45.103 | 54.729 | 57.378 | 59.139 | 60.094 |




Eigenvectors:

| | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|
| ΔT | 0.104 | 0.180 | 0.168 | 0.638 | 0.229 | −0.200 |
| pH | −0.107 | −0.549 | 0.139 | 0.430 | −0.363 | 0.178 |
| Turb | −0.377 | 0.510 | −0.183 | −0.009 | −0.072 | 0.614 |
| TSS | 0.263 | −0.157 | −0.902 | 0.036 | −0.158 | −0.110 |
| DO Def. | 0.490 | 0.335 | 0.151 | −0.280 | −0.165 | −0.022 |
| BOD5b | 0.428 | 0.032 | −0.019 | 0.350 | −0.092 | 0.608 |
| NO3−N | 0.033 | 0.513 | −0.072 | 0.399 | −0.341 | −0.394 |
| PO4−P | −0.347 | 0.024 | 0.071 | −0.096 | −0.715 | −0.106 |
| FCB | −0.471 | 0.062 | −0.269 | 0.195 | 0.350 | −0.059 |

Factor pattern:

| | F1 | F2 | F3 | al communa | al communa | ecific variance |
|---|---|---|---|---|---|---|
| ΔT | 0.172 | **0.208** | 0.156 | 0.202 | 0.097 | 0.903 |
| pH | −0.176 | **−0.635** | 0.129 | 0.494 | 0.451 | 0.549 |
| Turb | **−0.623** | 0.590 | −0.170 | 0.597 | 0.765 | 0.235 |
| TSS | 0.434 | −0.181 | **−0.840** | 0.259 | 0.926 | 0.074 |
| DO Def. | **0.809** | 0.387 | 0.141 | 0.666 | 0.824 | 0.176 |
| BOD5b | **0.706** | 0.036 | −0.017 | 0.533 | 0.500 | 0.500 |
| NO3−N | 0.054 | **0.593** | −0.067 | 0.329 | 0.359 | 0.641 |
| PO4−P | **−0.572** | 0.028 | 0.066 | 0.381 | 0.333 | 0.667 |
| FCB | **−0.777** | 0.072 | −0.250 | 0.626 | 0.671 | 0.329 |

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Correlations between variables and factors:

| | F1 | F2 | F3 |
|---|---|---|---|
| ΔT | 0.107 | −0.098 | 0.132 |
| pH | −0.160 | −0.774 | 0.175 |
| Turb | −0.437 | 0.652 | −0.714 |
| TSS | −0.041 | 0.266 | −0.944 |
| DO Def. | 0.873 | 0.600 | 0.207 |
| BOD5b | 0.727 | 0.108 | 0.146 |
| NO3−N | 0.131 | 0.460 | −0.112 |
| PO4−P | −0.600 | −0.056 | −0.235 |
| FCB | −0.721 | 0.049 | −0.723 |

Factor pattern and correlation after Varimax rotation:

| | D1 | D1 |
|---|---|---|
| ΔT | **0.172** | 0.107 |
| pH | **−0.176** | −0.160 |
| Turb | **−0.623** | −0.437 |
| TSS | **0.434** | −0.041 |
| DO Def. | **0.809** | 0.873 |
| BOD5b | **0.706** | 0.727 |
| NO3−N | **0.054** | 0.131 |
| PO4−P | **−0.572** | −0.600 |
| FCB | **−0.777** | −0.721 |

Appendix 11: Factor analysis results for Upper Shimanto and Lower Shimanto (eigenvalues, eigenvectors, factor pattern and scree plot)

Correlation matrix (Spearman): AGGREGATE

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | 0.028 | -0.054 | **-0.125** | **-0.149** | 0.023 | 0.034 | 0.005 | 0.022 | -0.069 |
| pH | 0.028 | **1** | **-0.256** | -0.021 | **-0.285** | **0.126** | **-0.522** | -0.075 | **-0.260** | 0.070 |
| Turb | -0.054 | **-0.256** | **1** | **0.634** | **-0.213** | -0.092 | **0.287** | **0.550** | **0.589** | **-0.366** |
| TSS | **-0.125** | -0.021 | **0.634** | **1** | **-0.125** | **0.135** | **0.212** | **0.457** | **0.400** | **-0.449** |
| DO Def. | **-0.149** | **-0.285** | **-0.213** | **-0.125** | **1** | **0.307** | **0.256** | **-0.400** | **-0.471** | 0.081 |
| BOD5b | 0.023 | **0.126** | -0.092 | **0.135** | **0.307** | **1** | 0.099 | **-0.291** | **-0.396** | **-0.593** |
| NO3-N | 0.034 | **-0.522** | **0.287** | **0.212** | **0.256** | 0.099 | **1** | **0.303** | **0.217** | **-0.283** |
| PO4-P | 0.005 | -0.075 | **0.550** | **0.457** | **-0.400** | **-0.291** | **0.303** | **1** | **0.679** | **-0.234** |
| FCB | 0.022 | **-0.260** | **0.589** | **0.400** | **-0.471** | **-0.396** | **0.217** | **0.679** | **1** | **-0.269** |
| WQI | -0.069 | 0.070 | **-0.366** | **-0.449** | 0.081 | **-0.593** | **-0.283** | **-0.234** | **-0.269** | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: AGGREGATE

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.615 | 0.335 | **0.025** | **0.008** | 0.687 | 0.542 | 0.927 | 0.700 | 0.220 |
| pH | 0.615 | **0** | **0.0001** | 0.706 | **0.0001** | **0.024** | **0.0001** | 0.184 | **0.0001** | 0.211 |
| Turb | 0.335 | **0.0001** | **0** | **0.0001** | **0.000** | 0.101 | **0.0001** | **0.0001** | **0.0001** | **0.0001** |
| TSS | **0.025** | 0.706 | **0.0001** | **0** | **0.025** | **0.016** | **0.000** | **0.0001** | **0.0001** | **0.0001** |
| DO Def. | **0.008** | **0.0001** | **0.000** | **0.025** | **0** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | 0.148 |
| BOD5b | 0.687 | **0.024** | 0.101 | **0.016** | **0.0001** | **0** | 0.076 | **0.0001** | **0.0001** | **0.0001** |
| NO3-N | 0.542 | **0.0001** | **0.0001** | **0.000** | **0.0001** | 0.076 | **0** | **0.0001** | **0.0001** | **0.0001** |
| PO4-P | 0.927 | 0.184 | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0** | **0.0001** | **0.0001** |
| FCB | 0.700 | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0** | **0.0001** |
| WQI | 0.220 | 0.211 | **0.0001** | **0.0001** | 0.148 | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): SPRING

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | 0.050 | -0.003 | -0.051 | -0.165 | 0.125 | 0.113 | 0.069 | 0.073 | **-0.260** |
| pH | 0.050 | **1** | **-0.217** | -0.152 | **-0.244** | -0.028 | **-0.623** | **-0.242** | **-0.213** | **0.257** |
| Turb | -0.003 | **-0.217** | **1** | **0.845** | **-0.330** | 0.209 | **0.483** | **0.763** | **0.758** | **-0.757** |
| TSS | -0.051 | -0.152 | **0.845** | **1** | **-0.345** | **0.324** | **0.372** | **0.654** | **0.664** | **-0.684** |
| DO Def. | -0.165 | **-0.244** | **-0.330** | **-0.345** | **1** | 0.065 | 0.119 | **-0.373** | **-0.430** | 0.147 |
| BOD5b | 0.125 | -0.028 | 0.209 | **0.324** | 0.065 | **1** | **0.354** | 0.143 | 0.053 | **-0.530** |
| NO3-N | 0.113 | **-0.623** | **0.483** | **0.372** | 0.119 | **0.354** | **1** | **0.523** | **0.359** | **-0.568** |
| PO4-P | 0.069 | **-0.242** | **0.763** | **0.654** | **-0.373** | 0.143 | **0.523** | **1** | **0.751** | **-0.672** |
| FCB | 0.073 | **-0.213** | **0.758** | **0.664** | **-0.430** | 0.053 | **0.359** | **0.751** | **1** | **-0.680** |
| WQI | **-0.260** | **0.257** | **-0.757** | **-0.684** | 0.147 | **-0.530** | **-0.568** | **-0.672** | **-0.680** | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: SPRING

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.641 | 0.981 | 0.638 | 0.125 | 0.245 | 0.293 | 0.521 | 0.498 | **0.015** |
| pH | 0.641 | **0** | **0.042** | 0.156 | **0.022** | 0.795 | **0.0001** | **0.024** | **0.046** | **0.016** |
| Turb | 0.981 | **0.042** | **0** | **0.0001** | **0.002** | 0.050 | **0.0001** | **0.0001** | **0.0001** | **0.0001** |
| TSS | 0.638 | 0.156 | **0.0001** | **0** | **0.001** | **0.002** | **0.000** | **0.0001** | **0.0001** | **0.0001** |
| DO Def. | 0.125 | **0.022** | **0.002** | **0.001** | **0** | 0.546 | 0.269 | **0.000** | **0.0001** | 0.171 |
| BOD5b | 0.245 | 0.795 | 0.050 | **0.002** | 0.546 | **0** | **0.001** | 0.184 | 0.623 | **0.0001** |
| NO3-N | 0.293 | **0.0001** | **0.0001** | **0.000** | 0.269 | **0.001** | **0** | **0.0001** | **0.001** | **0.0001** |
| PO4-P | 0.521 | **0.024** | **0.0001** | **0.0001** | **0.000** | 0.184 | **0.0001** | **0** | **0.0001** | **0.0001** |
| FCB | 0.498 | **0.046** | **0.0001** | **0.0001** | **0.0001** | 0.623 | **0.001** | **0.0001** | **0** | **0.0001** |
| WQI | **0.015** | **0.016** | **0.0001** | **0.0001** | 0.171 | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): SUMMER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | **0.220** | **-0.414** | **-0.261** | -0.116 | 0.123 | 0.059 | -0.129 | **-0.235** | -0.069 |
| pH | **0.220** | **1** | **-0.346** | -0.092 | **-0.279** | **0.246** | **-0.400** | 0.051 | **-0.443** | -0.164 |
| Turb | **-0.414** | **-0.346** | **1** | **0.617** | 0.161 | 0.006 | 0.135 | **0.444** | **0.503** | -0.151 |
| TSS | **-0.261** | -0.092 | **0.617** | **1** | -0.047 | 0.034 | 0.176 | **0.640** | **0.584** | **-0.338** |
| DO Def. | -0.116 | **-0.279** | 0.161 | -0.047 | **1** | **-0.335** | **0.226** | 0.107 | 0.052 | **0.438** |
| BOD5b | 0.123 | **0.246** | 0.006 | 0.034 | **-0.335** | **1** | -0.128 | 0.046 | 0.064 | **-0.733** |
| NO3-N | 0.059 | **-0.400** | 0.135 | 0.176 | **0.226** | -0.128 | **1** | **0.275** | **0.448** | -0.034 |
| PO4-P | -0.129 | 0.051 | **0.444** | **0.640** | 0.107 | 0.046 | **0.275** | **1** | **0.514** | **-0.371** |
| FCB | **-0.235** | **-0.443** | **0.503** | **0.584** | 0.052 | 0.064 | **0.448** | **0.514** | **1** | **-0.424** |
| WQI | -0.069 | -0.164 | -0.151 | **-0.338** | **0.438** | **-0.733** | -0.034 | **-0.371** | **-0.424** | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: SUMMER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | **0.031** | **0.0001** | **0.010** | 0.259 | 0.231 | 0.568 | 0.209 | **0.021** | 0.503 |
| pH | **0.031** | **0** | **0.001** | 0.370 | **0.006** | **0.016** | **0.0001** | 0.619 | **0.0001** | 0.111 |
| Turb | **0.0001** | **0.001** | **0** | **0.0001** | 0.118 | 0.956 | 0.190 | **0.0001** | **0.0001** | 0.141 |
| TSS | **0.010** | 0.370 | **0.0001** | **0** | 0.652 | 0.739 | 0.085 | **0.0001** | **0.0001** | **0.001** |
| DO Def. | 0.259 | **0.006** | 0.118 | 0.652 | **0** | **0.001** | **0.027** | 0.300 | 0.614 | **0.0001** |
| BOD5b | 0.231 | **0.016** | 0.956 | 0.739 | **0.001** | **0** | 0.213 | 0.654 | 0.538 | **0.0001** |
| NO3-N | 0.568 | **0.0001** | 0.190 | 0.085 | **0.027** | 0.213 | **0** | **0.007** | **0.0001** | 0.740 |
| PO4-P | 0.209 | 0.619 | **0.0001** | **0.0001** | 0.300 | 0.654 | **0.007** | **0** | **0.0001** | **0.000** |
| FCB | **0.021** | **0.0001** | **0.0001** | **0.0001** | 0.614 | 0.538 | **0.0001** | **0.0001** | **0** | **0.0001** |
| WQI | 0.503 | 0.111 | 0.141 | **0.001** | **0.0001** | **0.0001** | 0.740 | **0.000** | **0.0001** | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): FALL

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | -0.054 | **-0.247** | -0.152 | -0.023 | -0.037 | 0.079 | -0.029 | -0.171 | 0.088 |
| pH | -0.054 | **1** | **-0.335** | 0.157 | **-0.439** | 0.118 | **-0.703** | -0.240 | **-0.403** | -0.017 |
| Turb | **-0.247** | **-0.335** | **1** | **0.436** | 0.133 | 0.057 | **0.566** | **0.501** | **0.507** | **-0.317** |
| TSS | -0.152 | 0.157 | **0.436** | **1** | -0.005 | 0.075 | 0.219 | **0.509** | **0.288** | **-0.314** |
| DO Def. | -0.023 | **-0.439** | 0.133 | -0.005 | **1** | -0.226 | **0.305** | -0.182 | -0.034 | **0.342** |
| BOD5b | -0.037 | 0.118 | 0.057 | 0.075 | -0.226 | **1** | 0.053 | -0.061 | -0.214 | **-0.598** |
| NO3-N | 0.079 | **-0.703** | **0.566** | 0.219 | **0.305** | 0.053 | **1** | **0.518** | **0.489** | **-0.269** |
| PO4-P | -0.029 | -0.240 | **0.501** | **0.509** | -0.182 | -0.061 | **0.518** | **1** | **0.514** | **-0.279** |
| FCB | -0.171 | **-0.403** | **0.507** | **0.288** | -0.034 | -0.214 | **0.489** | **0.514** | **1** | **-0.342** |
| WQI | 0.088 | -0.017 | **-0.317** | **-0.314** | **0.342** | **-0.598** | **-0.269** | **-0.379** | **-0.342** | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: FALL

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.669 | **0.049** | 0.230 | 0.856 | 0.771 | 0.535 | 0.820 | 0.176 | 0.486 |
| pH | 0.669 | **0** | **0.007** | 0.213 | **0.000** | 0.351 | **0.0001** | 0.056 | **0.001** | 0.893 |
| Turb | **0.049** | **0.007** | **0** | **0.000** | 0.294 | 0.653 | **0.0001** | **0.0001** | **0.0001** | **0.011** |
| TSS | 0.230 | 0.213 | **0.000** | **0** | 0.966 | 0.554 | 0.082 | **0.0001** | **0.021** | **0.012** |
| DO Def. | 0.856 | **0.000** | 0.294 | 0.966 | **0** | 0.072 | **0.014** | 0.149 | 0.791 | **0.006** |
| BOD5b | 0.771 | 0.351 | 0.653 | 0.554 | 0.072 | **0** | 0.678 | 0.632 | 0.090 | **0.0001** |
| NO3-N | 0.535 | **0.0001** | **0.0001** | 0.082 | **0.014** | 0.678 | **0** | **0.0001** | **0.0001** | **0.032** |
| PO4-P | 0.820 | 0.056 | **0.0001** | **0.0001** | 0.149 | 0.632 | **0.0001** | **0** | **0.0001** | **0.026** |
| FCB | 0.176 | **0.001** | **0.0001** | **0.021** | 0.791 | 0.090 | **0.0001** | **0.0001** | **0** | **0.006** |
| WQI | 0.486 | 0.893 | **0.011** | **0.012** | **0.006** | **0.0001** | **0.002** | **0.026** | **0.006** | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): WINTER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | -0.103 | 0.197 | 0.024 | -0.150 | 0.075 | -0.026 | 0.166 | 0.214 | 0.088 |
| pH | -0.103 | **1** | -0.142 | 0.166 | **-0.586** | **0.407** | **-0.509** | -0.095 | **-0.546** | **0.284** |
| Turb | 0.197 | -0.142 | **1** | **0.634** | -0.187 | -0.145 | **0.497** | **0.563** | **0.620** | **-0.414** |
| TSS | 0.024 | 0.166 | **0.634** | **1** | **-0.275** | **0.384** | **0.300** | **0.273** | **0.357** | **-0.532** |
| DO Def. | -0.150 | **-0.586** | -0.187 | **-0.275** | **1** | -0.120 | -0.017 | **-0.338** | 0.043 | -0.224 |
| BOD5b | 0.075 | **0.407** | -0.145 | **0.384** | -0.120 | **1** | -0.143 | -0.118 | **-0.336** | **-0.293** |
| NO3-N | -0.026 | **-0.509** | **0.497** | **0.300** | -0.017 | -0.143 | **1** | **0.558** | **0.538** | **-0.468** |
| PO4-P | 0.166 | -0.095 | **0.563** | **0.273** | **-0.338** | -0.118 | **0.558** | **1** | **0.247** | -0.181 |
| FCB | 0.214 | **-0.546** | **0.620** | **0.357** | 0.043 | **-0.336** | **0.538** | **0.247** | **1** | **-0.356** |
| WQI | 0.088 | **0.284** | **-0.414** | **-0.532** | -0.224 | **-0.293** | **-0.468** | -0.181 | **-0.356** | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: WINTER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.387 | 0.098 | 0.843 | 0.207 | 0.531 | 0.826 | 0.162 | 0.072 | 0.461 |
| pH | 0.387 | **0** | 0.235 | 0.164 | **0.0001** | **0.000** | **0.0001** | 0.427 | **0.0001** | **0.016** |
| Turb | 0.098 | 0.235 | **0** | **0.0001** | 0.116 | 0.222 | **0.0001** | **0.0001** | **0.0001** | **0.000** |
| TSS | 0.843 | 0.164 | **0.0001** | **0** | **0.020** | **0.001** | **0.011** | **0.020** | **0.002** | **0.0001** |
| DO Def. | 0.207 | **0.0001** | 0.116 | **0.020** | **0** | 0.316 | 0.888 | **0.004** | 0.719 | 0.059 |
| BOD5b | 0.531 | **0.000** | 0.222 | **0.001** | 0.316 | **0** | 0.230 | 0.324 | **0.004** | **0.013** |
| NO3-N | 0.826 | **0.0001** | **0.0001** | **0.011** | 0.888 | 0.230 | **0** | **0.0001** | **0.0001** | **0.0001** |
| PO4-P | 0.162 | 0.427 | **0.0001** | **0.020** | **0.004** | 0.324 | **0.0001** | **0** | **0.036** | 0.128 |
| FCB | 0.072 | **0.0001** | **0.0001** | **0.002** | 0.719 | **0.004** | **0.0001** | **0.036** | **0** | **0.002** |
| WQI | 0.461 | **0.016** | **0.000** | **0.0001** | 0.059 | **0.013** | **0.0001** | 0.128 | **0.002** | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Appendix 12: Correlation analysis results using actual parameter values for aggregated and seasonal data

Correlation matrix (Spearman): 1. MIMA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | -0.247 | -0.002 | -0.119 | 0.179 | **0.368** | 0.160 | **-0.321** | -0.092 | **-0.409** |
| pH | -0.247 | 1 | **-0.341** | -0.207 | -0.077 | 0.111 | -0.189 | 0.138 | **-0.364** | **0.459** |
| Turb | -0.002 | **-0.341** | 1 | **0.707** | -0.124 | -0.179 | 0.143 | **0.362** | **0.529** | **-0.412** |
| TSS | -0.119 | -0.207 | **0.707** | 1 | -0.216 | -0.108 | 0.096 | **0.453** | **0.484** | **-0.332** |
| DO Def. | 0.179 | -0.077 | -0.124 | -0.216 | 1 | **0.332** | **0.329** | **-0.461** | **-0.499** | 0.021 |
| BOD5b | **0.368** | 0.111 | -0.179 | -0.108 | **0.332** | 1 | 0.054 | **-0.557** | **-0.499** | **-0.563** |
| NO3-N | 0.160 | -0.189 | 0.143 | 0.096 | **0.329** | 0.054 | 1 | 0.012 | -0.100 | -0.073 |
| PO4-P | **-0.321** | 0.138 | **0.362** | **0.453** | **-0.461** | **-0.557** | 0.012 | 1 | **0.693** | 0.109 |
| FCB | -0.092 | **-0.364** | **0.529** | **0.484** | **-0.499** | **-0.499** | -0.100 | **0.693** | 1 | -0.276 |
| WQI | **-0.409** | **0.459** | **-0.412** | **-0.332** | 0.021 | **-0.563** | -0.073 | 0.109 | -0.276 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 1. MIMA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.125 | 0.990 | 0.462 | 0.267 | **0.020** | 0.322 | **0.044** | 0.573 | **0.009** |
| pH | 0.125 | 0 | **0.032** | 0.199 | 0.634 | 0.492 | 0.242 | 0.392 | **0.021** | **0.003** |
| Turb | 0.990 | **0.032** | 0 | **0.0001** | 0.445 | 0.268 | 0.376 | **0.022** | **0.001** | **0.009** |
| TSS | 0.462 | 0.199 | **0.0001** | 0 | 0.181 | 0.508 | 0.554 | **0.004** | **0.002** | **0.037** |
| DO Def. | 0.267 | 0.634 | 0.445 | 0.181 | 0 | **0.037** | **0.039** | **0.003** | **0.001** | 0.895 |
| BOD5b | **0.020** | 0.492 | 0.268 | 0.508 | **0.037** | 0 | 0.740 | **0.000** | **0.001** | **0.000** |
| NO3-N | 0.322 | 0.242 | 0.376 | 0.554 | **0.039** | 0.740 | 0 | 0.941 | 0.538 | 0.656 |
| PO4-P | **0.044** | 0.392 | **0.022** | **0.004** | **0.003** | **0.000** | 0.941 | 0 | **0.0001** | 0.502 |
| FCB | 0.573 | **0.021** | **0.001** | **0.002** | **0.001** | **0.001** | 0.538 | **0.0001** | 0 | 0.085 |
| WQI | **0.009** | **0.003** | **0.009** | **0.037** | 0.895 | **0.000** | 0.656 | 0.502 | 0.085 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 2. NARA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | 0.102 | 0.126 | 0.069 | **-0.462** | **-0.352** | -0.116 | **0.313** | 0.274 | **0.313** |
| pH | 0.102 | 1 | -0.283 | 0.156 | 0.159 | 0.128 | -0.151 | 0.251 | -0.226 | **0.482** |
| Turb | 0.126 | -0.283 | 1 | -0.022 | **-0.433** | -0.074 | -0.050 | 0.138 | **0.442** | -0.205 |
| TSS | 0.069 | 0.156 | -0.022 | 1 | 0.030 | -0.197 | -0.162 | 0.154 | -0.085 | 0.233 |
| DO Def. | **-0.462** | 0.159 | **-0.433** | 0.030 | 1 | **0.381** | 0.118 | **-0.395** | **-0.673** | -0.127 |
| BOD5b | **-0.352** | 0.128 | -0.074 | -0.197 | **0.381** | 1 | 0.066 | **-0.410** | **-0.380** | **-0.705** |
| NO3-N | -0.116 | -0.151 | -0.050 | -0.162 | 0.118 | 0.066 | 1 | 0.017 | -0.069 | -0.165 |
| PO4-P | **0.313** | 0.251 | 0.138 | 0.154 | **-0.395** | **-0.410** | 0.017 | 1 | 0.299 | **0.469** |
| FCB | 0.274 | -0.226 | **0.442** | -0.085 | **-0.673** | **-0.380** | -0.069 | 0.299 | 1 | -0.031 |
| WQI | **0.313** | **0.482** | -0.205 | 0.233 | -0.127 | **-0.705** | -0.165 | **0.469** | -0.031 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 2. NARA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.531 | 0.437 | 0.672 | **0.003** | **0.026** | 0.475 | **0.050** | 0.087 | **0.050** |
| pH | 0.531 | 0 | 0.078 | 0.334 | 0.325 | 0.430 | 0.350 | 0.118 | 0.161 | **0.002** |
| Turb | 0.437 | 0.078 | 0 | 0.893 | **0.006** | 0.651 | 0.758 | 0.393 | **0.005** | 0.204 |
| TSS | 0.672 | 0.334 | 0.893 | 0 | 0.855 | 0.222 | 0.316 | 0.340 | 0.602 | 0.148 |
| DO Def. | **0.003** | 0.325 | **0.006** | 0.855 | 0 | **0.016** | 0.467 | **0.012** | **0.0001** | 0.433 |
| BOD5b | **0.026** | 0.430 | 0.651 | 0.222 | **0.016** | 0 | 0.683 | **0.009** | **0.016** | **0.0001** |
| NO3-N | 0.475 | 0.350 | 0.758 | 0.316 | 0.467 | 0.683 | 0 | 0.919 | 0.672 | 0.309 |
| PO4-P | **0.050** | 0.118 | 0.393 | 0.340 | **0.012** | **0.009** | 0.919 | 0 | 0.061 | **0.003** |
| FCB | 0.087 | 0.161 | **0.005** | 0.602 | **0.0001** | **0.016** | 0.672 | 0.061 | 0 | 0.852 |
| WQI | **0.050** | **0.002** | 0.204 | 0.148 | 0.433 | **0.0001** | 0.309 | **0.003** | 0.852 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 3. LOWER MIMA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | -0.005 | **0.436** | **0.539** | -0.264 | -0.251 | -0.161 | 0.220 | **0.324** | -0.089 |
| pH | -0.005 | 1 | **-0.605** | **-0.353** | -0.107 | 0.182 | **-0.418** | 0.019 | **-0.319** | -0.125 |
| Turb | **0.436** | **-0.605** | 1 | **0.702** | -0.056 | -0.281 | **0.320** | **0.355** | **0.452** | -0.156 |
| TSS | **0.539** | **-0.353** | **0.702** | 1 | -0.210 | -0.165 | 0.246 | 0.311 | **0.499** | -0.312 |
| DO Def. | -0.264 | -0.107 | -0.056 | -0.210 | 1 | 0.288 | **0.373** | **-0.331** | **-0.364** | 0.200 |
| BOD5b | -0.251 | 0.182 | -0.281 | -0.165 | 0.288 | 1 | -0.020 | **-0.533** | **-0.561** | **-0.526** |
| NO3-N | -0.161 | **-0.418** | **0.320** | 0.246 | **0.373** | -0.020 | 1 | 0.063 | -0.039 | 0.132 |
| PO4-P | 0.220 | 0.019 | **0.355** | 0.311 | **-0.331** | **-0.533** | 0.063 | 1 | **0.702** | -0.137 |
| FCB | **0.324** | **-0.319** | **0.452** | **0.499** | **-0.364** | **-0.561** | -0.039 | **0.702** | 1 | -0.107 |
| WQI | -0.089 | -0.125 | -0.156 | -0.312 | 0.200 | **-0.526** | 0.132 | -0.137 | -0.107 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 3. LOWER MIMA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.977 | **0.005** | **0.000** | 0.099 | 0.118 | 0.321 | 0.171 | **0.042** | 0.583 |
| pH | 0.977 | 0 | **0.0001** | **0.026** | 0.510 | 0.259 | **0.008** | 0.908 | **0.045** | 0.443 |
| Turb | **0.005** | **0.0001** | 0 | **0.0001** | 0.731 | 0.079 | **0.045** | **0.025** | **0.004** | 0.334 |
| TSS | **0.000** | **0.026** | **0.0001** | 0 | 0.193 | 0.307 | 0.126 | 0.051 | **0.001** | 0.051 |
| DO Def. | 0.099 | 0.510 | 0.731 | 0.193 | 0 | 0.072 | **0.018** | **0.038** | **0.022** | 0.214 |
| BOD5b | 0.118 | 0.259 | 0.079 | 0.307 | 0.072 | 0 | 0.903 | **0.000** | **0.000** | **0.001** |
| NO3-N | 0.321 | **0.008** | **0.045** | 0.126 | **0.018** | 0.903 | 0 | 0.697 | 0.810 | 0.415 |
| PO4-P | 0.171 | 0.908 | **0.025** | 0.051 | **0.038** | **0.000** | 0.697 | 0 | **0.0001** | 0.399 |
| FCB | **0.042** | **0.045** | **0.004** | **0.001** | **0.022** | **0.000** | 0.810 | **0.0001** | 0 | 0.510 |
| WQI | 0.583 | 0.443 | 0.334 | 0.051 | 0.214 | **0.001** | 0.415 | 0.399 | 0.510 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 4. HIROMI

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | 0.204 | 0.187 | 0.205 | -0.192 | 0.101 | -0.100 | 0.212 | 0.091 | **-0.441** |
| pH | 0.204 | 1 | **-0.322** | 0.250 | **-0.314** | 0.031 | -0.310 | 0.014 | -0.142 | **-0.428** |
| Turb | 0.187 | **-0.322** | 1 | 0.267 | -0.247 | -0.236 | **-0.332** | **0.382** | **0.411** | -0.017 |
| TSS | 0.205 | 0.250 | 0.267 | 1 | -0.292 | 0.135 | -0.190 | 0.148 | 0.036 | -0.289 |
| DO Def. | -0.192 | **-0.314** | -0.247 | -0.292 | 1 | 0.271 | **0.388** | **-0.556** | **-0.567** | **0.392** |
| BOD5b | 0.101 | 0.031 | -0.236 | 0.135 | 0.271 | 1 | 0.090 | **-0.421** | **-0.505** | **-0.545** |
| NO3-N | -0.100 | -0.310 | **-0.332** | -0.190 | **0.388** | 0.090 | 1 | -0.189 | -0.195 | 0.207 |
| PO4-P | 0.212 | 0.014 | **0.382** | 0.148 | **-0.556** | **-0.421** | -0.189 | 1 | **0.597** | -0.112 |
| FCB | 0.091 | -0.142 | **0.411** | 0.036 | **-0.567** | **-0.505** | -0.195 | **0.607** | 1 | -0.130 |
| WQI | **-0.441** | **-0.428** | -0.017 | -0.289 | **0.392** | **-0.545** | 0.207 | -0.112 | -0.130 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 4. HIROMI

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.205 | 0.245 | 0.204 | 0.235 | 0.534 | 0.540 | 0.188 | 0.576 | **0.005** |
| pH | 0.205 | 0 | **0.043** | 0.119 | **0.049** | 0.847 | 0.052 | 0.929 | 0.380 | **0.006** |
| Turb | 0.245 | **0.043** | 0 | 0.096 | 0.125 | 0.142 | **0.037** | **0.016** | **0.009** | 0.916 |
| TSS | 0.204 | 0.119 | 0.096 | 0 | 0.068 | 0.403 | 0.238 | 0.361 | 0.823 | 0.070 |
| DO Def. | 0.235 | **0.049** | 0.125 | 0.068 | 0 | 0.090 | **0.014** | **0.000** | **0.000** | **0.013** |
| BOD5b | 0.534 | 0.847 | 0.142 | 0.403 | 0.090 | 0 | 0.578 | **0.007** | **0.001** | **0.000** |
| NO3-N | 0.540 | 0.052 | **0.037** | 0.238 | **0.014** | 0.578 | 0 | 0.243 | 0.227 | 0.200 |
| PO4-P | 0.188 | 0.929 | **0.016** | 0.361 | **0.000** | **0.007** | 0.243 | 0 | **0.0001** | 0.491 |
| FCB | 0.576 | 0.380 | **0.009** | 0.823 | **0.000** | **0.001** | 0.227 | **0.0001** | 0 | 0.423 |
| WQI | **0.005** | **0.006** | 0.916 | 0.070 | **0.013** | **0.000** | 0.200 | 0.491 | 0.423 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Appendix 13: Correlation analysis results using actual parameter values for Mima, Nara, Lower Mima and Hiromi

Correlation matrix (Spearman): 5. HIROMI-MIMA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | -0.284 | -0.070 | -0.176 | 0.051 | 0.213 | 0.220 | -0.125 | 0.035 | -0.227 |
| pH | -0.284 | **1** | **-0.329** | -0.069 | 0.080 | 0.079 | -0.234 | 0.033 | -0.179 | 0.229 |
| Turb | -0.070 | **-0.329** | **1** | **0.588** | -0.306 | -0.262 | 0.050 | **0.416** | **0.462** | -0.044 |
| TSS | -0.176 | -0.069 | **0.688** | **1** | -0.172 | -0.123 | 0.010 | 0.193 | 0.301 | -0.117 |
| DO Def. | 0.051 | 0.080 | -0.306 | -0.172 | **1** | **0.358** | 0.227 | **-0.636** | **-0.592** | -0.117 |
| BOD5b | 0.213 | 0.079 | -0.262 | -0.123 | **0.358** | **1** | 0.296 | **-0.403** | **-0.575** | **-0.755** |
| NO3-N | 0.220 | -0.234 | 0.050 | 0.010 | 0.227 | 0.296 | **1** | -0.037 | -0.167 | -0.268 |
| PO4-P | -0.125 | 0.033 | **0.416** | 0.193 | **-0.636** | **-0.403** | -0.037 | **1** | **0.661** | 0.123 |
| FCB | 0.035 | -0.179 | **0.462** | 0.301 | **-0.592** | **-0.575** | -0.167 | **0.661** | **1** | 0.101 |
| WQI | -0.227 | 0.229 | -0.044 | -0.117 | -0.117 | **-0.755** | -0.268 | 0.123 | 0.101 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 5. HIROMI-MIMA

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.076 | 0.666 | 0.275 | 0.753 | 0.187 | 0.171 | 0.439 | 0.831 | 0.159 |
| pH | 0.076 | **0** | **0.039** | 0.673 | 0.624 | 0.624 | 0.145 | 0.840 | 0.269 | 0.154 |
| Turb | 0.666 | **0.039** | **0** | **0.0001** | 0.055 | 0.103 | 0.760 | **0.008** | **0.003** | 0.789 |
| TSS | 0.275 | 0.673 | **0.0001** | **0** | 0.288 | 0.448 | 0.952 | 0.232 | 0.059 | 0.469 |
| DO Def. | 0.753 | 0.624 | 0.055 | 0.288 | **0** | **0.024** | 0.159 | **0.0001** | **0.0001** | 0.473 |
| BOD5b | 0.187 | 0.624 | 0.103 | 0.448 | **0.024** | **0** | 0.064 | **0.010** | **0.000** | **0.0001** |
| NO3-N | 0.171 | 0.145 | 0.760 | 0.952 | 0.159 | 0.064 | **0** | 0.820 | 0.302 | 0.094 |
| PO4-P | 0.439 | 0.840 | **0.008** | 0.232 | **0.0001** | **0.010** | 0.820 | **0** | **0.0001** | 0.448 |
| FCB | 0.831 | 0.269 | **0.003** | 0.059 | **0.0001** | **0.000** | 0.302 | **0.0001** | **0** | 0.533 |
| WQI | 0.159 | 0.154 | 0.789 | 0.469 | 0.473 | **0.0001** | 0.094 | 0.448 | 0.533 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 6. LOWER HIROMI

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | 0.258 | 0.134 | -0.291 | **-0.547** | -0.205 | **-0.343** | 0.197 | 0.090 | -0.155 |
| pH | 0.258 | **1** | -0.231 | 0.070 | **-0.458** | 0.099 | **-0.550** | 0.079 | -0.168 | **-0.584** |
| Turb | 0.134 | -0.231 | **1** | 0.245 | -0.190 | **-0.351** | 0.213 | **0.457** | **0.598** | -0.057 |
| TSS | -0.291 | 0.070 | 0.245 | **1** | -0.191 | 0.092 | -0.111 | -0.029 | 0.145 | -0.277 |
| DO Def. | **-0.547** | **-0.458** | -0.190 | -0.191 | **1** | 0.260 | **0.545** | -0.301 | **-0.405** | **0.454** |
| BOD5b | -0.205 | 0.099 | **-0.351** | 0.092 | 0.260 | **1** | 0.097 | **-0.570** | **-0.493** | **-0.470** |
| NO3-N | **-0.343** | **-0.550** | 0.213 | -0.111 | **0.545** | 0.097 | **1** | -0.048 | -0.115 | 0.296 |
| PO4-P | 0.197 | 0.079 | **0.457** | -0.029 | -0.301 | **-0.570** | -0.048 | **1** | **0.645** | 0.049 |
| FCB | 0.090 | -0.168 | **0.598** | 0.145 | **-0.405** | **-0.493** | -0.115 | **0.645** | **1** | -0.038 |
| WQI | -0.155 | **-0.584** | -0.057 | -0.277 | **0.454** | **-0.470** | 0.296 | 0.049 | -0.038 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 6. LOWER HIROMI

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.108 | 0.409 | 0.069 | **0.000** | 0.204 | **0.031** | 0.222 | 0.581 | 0.337 |
| pH | 0.108 | **0** | 0.152 | 0.668 | **0.003** | 0.540 | **0.000** | 0.624 | 0.298 | **0.000** |
| Turb | 0.409 | 0.152 | **0** | 0.127 | 0.241 | **0.027** | 0.186 | **0.003** | **0.0001** | 0.725 |
| TSS | 0.069 | 0.668 | 0.127 | **0** | 0.236 | 0.570 | 0.493 | 0.856 | 0.370 | 0.084 |
| DO Def. | **0.000** | **0.003** | 0.241 | 0.236 | **0** | 0.105 | **0.000** | 0.060 | **0.010** | **0.004** |
| BOD5b | 0.204 | 0.540 | **0.027** | 0.570 | 0.105 | **0** | 0.548 | **0.000** | **0.001** | **0.002** |
| NO3-N | **0.031** | **0.000** | 0.186 | 0.493 | **0.000** | 0.548 | **0** | 0.770 | 0.480 | 0.064 |
| PO4-P | 0.222 | 0.624 | **0.003** | 0.856 | 0.060 | **0.000** | 0.770 | **0** | **0.0001** | 0.763 |
| FCB | 0.581 | 0.298 | **0.0001** | 0.370 | **0.010** | **0.001** | 0.480 | **0.0001** | **0** | 0.813 |
| WQI | 0.337 | **0.000** | 0.725 | 0.084 | **0.004** | **0.002** | 0.064 | 0.763 | 0.813 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 7. UPPER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | **0.342** | 0.050 | -0.254 | **-0.379** | -0.299 | **-0.403** | 0.185 | 0.144 | **0.324** |
| pH | **0.342** | **1** | **-0.319** | 0.012 | -0.240 | -0.003 | -0.241 | **0.402** | -0.044 | -0.102 |
| Turb | 0.050 | **-0.319** | **1** | **-0.535** | **-0.383** | **-0.456** | **0.339** | **0.398** | **0.598** | 0.102 |
| TSS | -0.254 | 0.012 | **-0.535** | **1** | **0.430** | 0.232 | -0.282 | -0.197 | **-0.379** | -0.116 |
| DO Def. | **-0.379** | -0.240 | **-0.383** | **0.430** | **1** | **0.589** | 0.202 | **-0.383** | **-0.599** | **-0.319** |
| BOD5b | -0.299 | -0.003 | **-0.456** | 0.232 | **0.589** | **1** | -0.041 | **-0.358** | **-0.547** | **-0.741** |
| NO3-N | **-0.403** | -0.241 | **0.339** | -0.282 | 0.202 | -0.041 | **1** | 0.093 | 0.061 | 0.027 |
| PO4-P | 0.185 | **0.402** | **0.398** | -0.197 | **-0.383** | **-0.358** | 0.093 | **1** | **0.371** | 0.021 |
| FCB | 0.144 | -0.044 | **0.598** | **-0.379** | **-0.599** | **-0.547** | 0.061 | **0.371** | **1** | 0.121 |
| WQI | **0.324** | -0.102 | 0.102 | -0.116 | **-0.319** | **-0.741** | 0.027 | 0.021 | 0.121 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 7. UPPER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | **0.031** | 0.758 | 0.114 | **0.016** | 0.062 | **0.010** | 0.252 | 0.372 | **0.042** |
| pH | **0.031** | **0** | **0.045** | 0.943 | 0.135 | 0.987 | 0.134 | **0.011** | 0.787 | 0.528 |
| Turb | 0.758 | **0.045** | **0** | **0.000** | **0.015** | **0.003** | **0.033** | **0.012** | **0.0001** | 0.528 |
| TSS | 0.114 | 0.943 | **0.000** | **0** | **0.006** | 0.150 | 0.078 | 0.222 | **0.016** | 0.475 |
| DO Def. | **0.016** | 0.135 | **0.015** | **0.006** | **0** | **0.0001** | 0.210 | **0.015** | **0.0001** | **0.045** |
| BOD5b | 0.062 | 0.987 | **0.003** | 0.150 | **0.0001** | **0** | 0.803 | **0.024** | **0.000** | **0.0001** |
| NO3-N | **0.010** | 0.134 | **0.033** | 0.078 | 0.210 | 0.803 | **0** | 0.567 | 0.707 | 0.866 |
| PO4-P | 0.252 | **0.011** | **0.012** | 0.222 | **0.015** | **0.024** | 0.567 | **0** | **0.019** | 0.898 |
| FCB | 0.372 | 0.787 | **0.0001** | **0.016** | **0.0001** | **0.000** | 0.707 | **0.019** | **0** | 0.455 |
| WQI | **0.042** | 0.528 | 0.528 | 0.475 | **0.045** | **0.0001** | 0.866 | 0.898 | 0.455 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 8. LOWER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | -0.057 | -0.050 | -0.127 | 0.194 | 0.186 | 0.262 | -0.187 | -0.074 | -0.104 |
| pH | -0.057 | **1** | -0.305 | -0.056 | **-0.423** | -0.049 | **-0.378** | 0.192 | 0.064 | -0.012 |
| Turb | -0.050 | -0.305 | **1** | -0.252 | **-0.320** | **-0.338** | **0.321** | **0.385** | **0.586** | -0.006 |
| TSS | -0.127 | -0.056 | -0.252 | **1** | 0.160 | **0.329** | 0.013 | -0.304 | -0.131 | -0.154 |
| DO Def. | 0.194 | **-0.423** | **-0.320** | 0.160 | **1** | **0.592** | 0.241 | **-0.390** | **-0.651** | -0.224 |
| BOD5b | 0.186 | -0.049 | **-0.338** | **0.329** | **0.592** | **1** | 0.074 | **-0.446** | **-0.563** | **-0.655** |
| NO3-N | 0.262 | **-0.378** | **0.321** | 0.013 | 0.241 | 0.074 | **1** | 0.076 | -0.008 | 0.123 |
| PO4-P | -0.187 | 0.192 | **0.385** | -0.304 | **-0.390** | **-0.446** | 0.076 | **1** | **0.392** | 0.131 |
| FCB | -0.074 | 0.064 | **0.586** | -0.131 | **-0.651** | **-0.563** | -0.008 | **0.392** | **1** | 0.003 |
| WQI | -0.104 | -0.012 | -0.006 | -0.154 | -0.224 | **-0.655** | 0.123 | 0.131 | 0.003 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 8. LOWER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.724 | 0.758 | 0.433 | 0.229 | 0.250 | 0.102 | 0.247 | 0.650 | 0.522 |
| pH | 0.724 | **0** | 0.056 | 0.728 | **0.007** | 0.763 | **0.017** | 0.235 | 0.694 | 0.942 |
| Turb | 0.758 | 0.056 | **0** | 0.116 | **0.045** | **0.033** | **0.044** | **0.015** | **0.0001** | 0.972 |
| TSS | 0.433 | 0.728 | 0.116 | **0** | 0.321 | **0.039** | 0.936 | 0.057 | 0.420 | 0.341 |
| DO Def. | 0.229 | **0.007** | **0.045** | 0.321 | **0** | **0.0001** | 0.133 | **0.013** | **0.0001** | 0.165 |
| BOD5b | 0.250 | 0.763 | **0.033** | **0.039** | **0.0001** | **0** | 0.649 | **0.004** | **0.000** | **0.0001** |
| NO3-N | 0.102 | **0.017** | **0.044** | 0.936 | 0.133 | 0.649 | **0** | 0.639 | 0.963 | 0.446 |
| PO4-P | 0.247 | 0.235 | **0.015** | 0.057 | **0.013** | **0.004** | 0.639 | **0** | **0.013** | 0.417 |
| FCB | 0.650 | 0.694 | **0.0001** | 0.420 | **0.0001** | **0.000** | 0.963 | **0.013** | **0** | 0.984 |
| WQI | 0.522 | 0.942 | 0.972 | 0.341 | 0.165 | **0.0001** | 0.446 | 0.417 | 0.984 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Appendix 14: Correlation analysis results using actual parameter values for Hiromi-Mima confluence, Lower Hiromi, Upper Shimanto and Lower Shimanto

Correlation matrix (Spearman): AGGREGATE

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | **0.178** | **0.131** | **-0.192** | 0.013 | -0.078 | 0.006 | **0.243** | **0.187** | **0.169** |
| pH | **0.178** | 1 | -0.091 | -0.065 | -0.013 | -0.017 | **0.137** | **0.112** | **0.153** | **0.388** |
| Turb | **0.131** | -0.091 | 1 | **-0.644** | -0.047 | -0.093 | **0.180** | **0.453** | **0.576** | **0.360** |
| TSS | **-0.192** | -0.065 | **-0.644** | 1 | 0.039 | 0.012 | **-0.113** | **-0.451** | **-0.500** | **0.373** |
| DO Def. | 0.013 | -0.013 | -0.047 | 0.039 | 1 | **0.255** | -0.095 | **-0.160** | -0.087 | **0.419** |
| BOD5b | -0.078 | -0.017 | -0.093 | 0.012 | **0.255** | 1 | 0.012 | **-0.251** | **-0.392** | **0.591** |
| NO3-N | 0.006 | **0.137** | **0.180** | **-0.113** | -0.095 | 0.012 | 1 | **0.150** | **0.155** | **0.196** |
| PO4-P | **0.243** | **0.112** | **0.453** | **-0.451** | **-0.160** | **-0.251** | **0.150** | 1 | **0.616** | **0.205** |
| FCB | **0.187** | **0.153** | **0.576** | **-0.500** | -0.087 | **-0.392** | **0.155** | **0.616** | 1 | **0.278** |
| WQI | **0.169** | **0.388** | **0.360** | **0.373** | **0.419** | **0.591** | **0.196** | **0.205** | **0.278** | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: AGGREGATE

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | **0.001** | **0.019** | **0.001** | 0.820 | 0.165 | 0.921 | **0.0001** | **0.001** | **0.002** |
| pH | **0.001** | 0 | 0.106 | 0.243 | 0.818 | 0.768 | **0.014** | **0.045** | **0.006** | **0.0001** |
| Turb | **0.019** | 0.106 | 0 | **0.0001** | 0.398 | 0.097 | **0.001** | **0.0001** | **0.0001** | **0.0001** |
| TSS | **0.001** | 0.243 | **0.0001** | 0 | 0.487 | 0.835 | **0.044** | **0.0001** | **0.0001** | **0.0001** |
| DO Def. | 0.820 | 0.818 | 0.398 | 0.487 | 0 | **0.0001** | 0.088 | **0.004** | 0.122 | **0.0001** |
| BOD5b | 0.165 | 0.768 | 0.097 | 0.835 | **0.0001** | 0 | 0.833 | **0.0001** | **0.0001** | **0.0001** |
| NO3-N | 0.921 | **0.014** | **0.001** | **0.044** | 0.088 | 0.833 | 0 | **0.007** | **0.006** | **0.000** |
| PO4-P | **0.0001** | **0.045** | **0.0001** | **0.0001** | **0.004** | **0.0001** | **0.007** | 0 | **0.0001** | **0.000** |
| FCB | **0.001** | **0.006** | **0.0001** | **0.0001** | 0.122 | **0.0001** | **0.006** | **0.0001** | 0 | **0.0001** |
| WQI | **0.002** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.000** | **0.000** | **0.0001** | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): SPRING

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | **0.331** | **0.314** | **-0.388** | 0.010 | 0.104 | 0.003 | **0.423** | **0.326** | **0.383** |
| pH | **0.331** | 1 | 0.117 | **-0.212** | -0.070 | -0.085 | 0.205 | 0.180 | 0.184 | **0.318** |
| Turb | **0.314** | 0.117 | 1 | **-0.837** | 0.026 | **0.217** | **0.270** | **0.642** | **0.756** | **0.752** |
| TSS | **-0.388** | **-0.212** | **-0.837** | 1 | -0.044 | **-0.264** | -0.196 | **-0.690** | **-0.682** | **0.726** |
| DO Def. | 0.010 | -0.070 | 0.026 | -0.044 | 1 | 0.193 | -0.113 | -0.039 | -0.014 | **0.340** |
| BOD5b | 0.104 | -0.085 | **0.217** | **-0.264** | 0.193 | 1 | 0.072 | 0.154 | 0.059 | **0.539** |
| NO3-N | 0.003 | 0.205 | **0.270** | -0.196 | -0.113 | 0.072 | 1 | **0.244** | **0.223** | **0.275** |
| PO4-P | **0.423** | 0.180 | **0.642** | **-0.690** | -0.039 | 0.154 | **0.244** | 1 | **0.670** | **0.590** |
| FCB | **0.326** | 0.184 | **0.756** | **-0.682** | -0.014 | 0.059 | **0.223** | **0.670** | 1 | **0.692** |
| WQI | **0.383** | **0.318** | **0.752** | **0.726** | **0.340** | **0.539** | **0.275** | **0.590** | **0.692** | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: SPRING

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | **0.002** | **0.003** | **0.000** | 0.929 | 0.334 | 0.975 | **0.0001** | **0.002** | **0.000** |
| pH | **0.002** | 0 | 0.275 | **0.047** | 0.517 | 0.431 | 0.056 | 0.092 | 0.085 | **0.003** |
| Turb | **0.003** | 0.275 | 0 | **0.0001** | 0.812 | **0.043** | **0.011** | **0.0001** | **0.0001** | **0.0001** |
| TSS | **0.000** | **0.047** | **0.0001** | 0 | 0.683 | **0.013** | 0.067 | **0.0001** | **0.0001** | **0.0001** |
| DO Def. | 0.929 | 0.517 | 0.812 | 0.683 | 0 | 0.072 | 0.293 | 0.720 | 0.895 | **0.001** |
| BOD5b | 0.334 | 0.431 | **0.043** | **0.013** | 0.072 | 0 | 0.504 | 0.152 | 0.582 | **0.0001** |
| NO3-N | 0.975 | 0.056 | **0.011** | 0.067 | 0.293 | 0.504 | 0 | **0.022** | **0.037** | **0.010** |
| PO4-P | **0.0001** | 0.092 | **0.0001** | **0.0001** | 0.720 | 0.152 | **0.022** | 0 | **0.0001** | **0.0001** |
| FCB | **0.002** | 0.085 | **0.0001** | **0.0001** | 0.895 | 0.582 | **0.037** | **0.0001** | 0 | **0.0001** |
| WQI | **0.000** | **0.003** | **0.0001** | **0.0001** | **0.001** | **0.0001** | **0.010** | **0.0001** | **0.0001** | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): SUMMER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | 0.080 | -0.196 | 0.025 | -0.051 | -0.126 | 0.087 | 0.160 | 0.098 | 0.079 |
| pH | 0.080 | 1 | **-0.254** | 0.053 | **0.294** | **0.221** | -0.156 | -0.034 | -0.036 | **0.539** |
| Turb | -0.196 | **-0.254** | 1 | **-0.669** | **-0.201** | -0.004 | 0.127 | **0.384** | **0.521** | 0.154 |
| TSS | 0.025 | 0.053 | **-0.669** | 1 | 0.173 | -0.057 | -0.130 | **-0.430** | **-0.601** | **0.275** |
| DO Def. | -0.051 | **0.294** | **-0.201** | 0.173 | 1 | **0.316** | -0.022 | -0.018 | -0.040 | **0.470** |
| BOD5b | -0.126 | **0.221** | -0.004 | -0.057 | **0.316** | 1 | -0.137 | 0.056 | 0.058 | **0.719** |
| NO3-N | 0.087 | -0.156 | 0.127 | -0.130 | -0.022 | -0.137 | 1 | 0.039 | 0.166 | 0.028 |
| PO4-P | 0.160 | -0.034 | **0.384** | **-0.430** | -0.018 | 0.056 | 0.039 | 1 | **0.458** | **0.339** |
| FCB | 0.098 | -0.036 | **0.521** | **-0.601** | -0.040 | 0.058 | 0.166 | **0.458** | 1 | **0.426** |
| WQI | 0.079 | **0.539** | 0.154 | **0.275** | **0.470** | **0.719** | 0.028 | **0.339** | **0.426** | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: SUMMER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.436 | 0.056 | 0.810 | 0.621 | 0.219 | 0.399 | 0.119 | 0.342 | 0.442 |
| pH | 0.436 | 0 | **0.013** | 0.609 | **0.004** | **0.030** | 0.129 | 0.744 | 0.730 | **0.0001** |
| Turb | 0.056 | **0.013** | 0 | **0.0001** | **0.050** | 0.969 | 0.218 | **0.000** | **0.0001** | 0.135 |
| TSS | 0.810 | 0.609 | **0.0001** | 0 | 0.093 | 0.579 | 0.208 | **0.0001** | **0.0001** | **0.007** |
| DO Def. | 0.621 | **0.004** | **0.050** | 0.093 | 0 | **0.002** | 0.828 | 0.863 | 0.697 | **0.0001** |
| BOD5b | 0.219 | **0.030** | 0.969 | 0.579 | **0.002** | 0 | 0.182 | 0.587 | 0.575 | **0.0001** |
| NO3-N | 0.399 | 0.129 | 0.218 | 0.208 | 0.828 | 0.182 | 0 | 0.706 | 0.107 | 0.788 |
| PO4-P | 0.119 | 0.744 | **0.000** | **0.0001** | 0.863 | 0.587 | 0.706 | 0 | **0.0001** | **0.001** |
| FCB | 0.342 | 0.730 | **0.0001** | **0.0001** | 0.697 | 0.575 | 0.107 | **0.0001** | 0 | **0.0001** |
| WQI | 0.442 | **0.0001** | 0.135 | **0.007** | **0.0001** | **0.0001** | 0.788 | **0.001** | **0.0001** | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): FALL

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | 0.023 | 0.034 | -0.203 | 0.168 | -0.056 | -0.059 | 0.223 | -0.058 | 0.083 |
| pH | 0.023 | 1 | **-0.282** | -0.092 | 0.097 | **0.274** | 0.213 | -0.053 | -0.094 | **0.589** |
| Turb | 0.034 | **-0.282** | 1 | **-0.258** | -0.021 | 0.085 | **0.370** | **0.406** | **0.451** | **0.307** |
| TSS | -0.203 | -0.092 | **-0.258** | 1 | 0.003 | 0.140 | -0.175 | **-0.384** | -0.233 | 0.136 |
| DO Def. | 0.168 | 0.097 | -0.021 | 0.003 | 1 | 0.231 | -0.179 | 0.046 | -0.011 | **0.299** |
| BOD5b | -0.056 | **0.274** | 0.085 | 0.140 | 0.231 | 1 | 0.102 | -0.087 | -0.211 | **0.597** |
| NO3-N | -0.059 | 0.213 | **0.370** | -0.175 | -0.179 | 0.102 | 1 | 0.132 | **0.382** | **0.368** |
| PO4-P | 0.223 | -0.053 | **0.406** | **-0.384** | 0.046 | -0.087 | 0.132 | 1 | **0.464** | **0.303** |
| FCB | -0.058 | -0.094 | **0.451** | -0.233 | -0.011 | -0.211 | **0.382** | **0.464** | 1 | **0.353** |
| WQI | 0.083 | **0.289** | **0.307** | 0.136 | **0.299** | **0.597** | **0.303** | **0.368** | **0.353** | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: FALL

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.856 | 0.790 | 0.107 | 0.185 | 0.661 | 0.640 | 0.076 | 0.648 | 0.515 |
| pH | 0.856 | 0 | **0.025** | 0.467 | 0.446 | **0.029** | 0.092 | 0.679 | 0.461 | **0.0001** |
| Turb | 0.790 | **0.025** | 0 | **0.040** | 0.869 | 0.502 | **0.003** | **0.001** | **0.000** | **0.014** |
| TSS | 0.107 | 0.467 | **0.040** | 0 | 0.982 | 0.270 | 0.165 | **0.002** | 0.064 | 0.284 |
| DO Def. | 0.185 | 0.446 | 0.869 | 0.982 | 0 | 0.066 | 0.157 | 0.718 | 0.934 | **0.017** |
| BOD5b | 0.661 | **0.029** | 0.502 | 0.270 | 0.066 | 0 | 0.419 | 0.493 | 0.094 | **0.0001** |
| NO3-N | 0.640 | 0.092 | **0.003** | 0.165 | 0.157 | 0.419 | 0 | 0.297 | **0.002** | **0.003** |
| PO4-P | 0.076 | 0.679 | **0.001** | **0.002** | 0.718 | 0.493 | 0.297 | 0 | **0.000** | **0.015** |
| FCB | 0.648 | 0.461 | **0.000** | 0.064 | 0.934 | 0.094 | **0.002** | **0.000** | 0 | **0.004** |
| WQI | 0.515 | **0.020** | **0.010** | 0.284 | **0.017** | **0.0001** | **0.003** | **0.010** | **0.004** | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): WINTER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | **0.326** | 0.172 | -0.017 | -0.056 | -0.011 | 0.148 | 0.148 | **0.250** | **0.246** |
| pH | **0.326** | 1 | 0.059 | -0.205 | -0.224 | 0.084 | 0.186 | 0.024 | 0.191 | **0.489** |
| Turb | 0.172 | 0.059 | 1 | **-0.387** | -0.165 | -0.190 | **0.312** | **0.467** | **0.618** | **0.421** |
| TSS | -0.017 | -0.205 | **-0.387** | 1 | 0.206 | 0.167 | **-0.383** | **-0.369** | **-0.460** | **0.274** |
| DO Def. | -0.056 | -0.224 | -0.165 | 0.206 | 1 | -0.081 | -0.023 | **-0.418** | 0.046 | **0.283** |
| BOD5b | -0.011 | 0.084 | -0.190 | 0.167 | -0.081 | 1 | **-0.311** | **-0.321** | **-0.289** | **0.286** |
| NO3-N | 0.148 | 0.186 | **0.312** | **-0.383** | -0.023 | **-0.311** | 1 | **0.372** | **0.352** | **0.257** |
| PO4-P | 0.148 | 0.024 | **0.467** | **-0.369** | **-0.418** | **-0.321** | **0.372** | 1 | **0.305** | 0.053 |
| FCB | **0.250** | 0.191 | **0.618** | **-0.460** | 0.046 | **-0.289** | **0.352** | **0.305** | 1 | **0.399** |
| WQI | **0.246** | **0.289** | **0.421** | **0.374** | **0.283** | **0.286** | **0.257** | 0.053 | **0.399** | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: WINTER

| Variables | ΔT | pH | Turb | TSS | DO Def. | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | **0.005** | 0.148 | 0.889 | 0.642 | 0.924 | 0.215 | 0.215 | **0.034** | **0.037** |
| pH | **0.005** | 0 | 0.622 | 0.084 | 0.059 | 0.482 | 0.117 | 0.843 | 0.107 | **0.0001** |
| Turb | 0.148 | 0.622 | 0 | **0.001** | 0.165 | 0.111 | **0.008** | **0.0001** | **0.0001** | **0.000** |
| TSS | 0.889 | 0.084 | **0.001** | 0 | 0.083 | 0.159 | **0.001** | **0.002** | **0.0001** | **0.020** |
| DO Def. | 0.642 | 0.059 | 0.165 | 0.083 | 0 | 0.497 | 0.845 | **0.000** | 0.699 | **0.016** |
| BOD5b | 0.924 | 0.482 | 0.111 | 0.159 | 0.497 | 0 | **0.008** | **0.006** | **0.014** | **0.015** |
| NO3-N | 0.215 | 0.117 | **0.008** | **0.001** | 0.845 | **0.008** | 0 | **0.001** | **0.003** | **0.030** |
| PO4-P | 0.215 | 0.843 | **0.0001** | **0.002** | **0.000** | **0.006** | **0.001** | 0 | **0.009** | 0.658 |
| FCB | **0.034** | 0.107 | **0.0001** | **0.0001** | 0.699 | **0.014** | **0.003** | **0.009** | 0 | **0.001** |
| WQI | **0.037** | **0.029** | **0.000** | **0.002** | **0.016** | **0.015** | **0.030** | 0.658 | **0.001** | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Appendix 15: Correlation analysis results using parameter index values for aggregated and seasonal data

Correlation matrix (Spearman): 1. MIMA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | 0.010 | 0.070 | 0.021 | -0.046 | -0.142 | -0.150 | -0.016 | 0.144 | 0.009 |
| pH | 0.010 | 1 | **0.325** | -0.250 | 0.235 | -0.025 | 0.247 | -0.259 | **0.377** | **0.543** |
| Turb | 0.070 | **0.325** | 1 | **-0.762** | -0.008 | -0.183 | 0.092 | **0.372** | **0.526** | **0.422** |
| TSS | 0.021 | -0.250 | **-0.762** | 1 | 0.072 | 0.147 | 0.089 | **-0.498** | **-0.524** | **0.345** |
| DO Def. | -0.046 | 0.235 | -0.008 | 0.072 | 1 | 0.174 | -0.112 | -0.197 | -0.047 | **0.417** |
| BOD5b | -0.142 | -0.025 | -0.183 | 0.147 | 0.174 | 1 | -0.035 | **-0.408** | **-0.508** | **0.558** |
| NO3-N | -0.150 | 0.247 | 0.092 | 0.089 | -0.112 | -0.035 | 1 | -0.024 | 0.035 | 0.087 |
| PO4-P | -0.016 | -0.259 | **0.372** | **-0.498** | -0.197 | **-0.408** | -0.024 | 1 | **0.556** | 0.045 |
| FCB | 0.144 | **0.377** | **0.526** | **-0.524** | -0.047 | **-0.508** | 0.035 | **0.556** | 1 | 0.280 |
| WQI | 0.009 | **0.543** | **0.422** | **0.345** | **0.417** | **0.558** | 0.087 | 0.045 | 0.280 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 1. MIMA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.950 | 0.668 | 0.896 | 0.776 | 0.382 | 0.353 | 0.924 | 0.373 | 0.954 |
| pH | 0.950 | 0 | **0.041** | 0.119 | 0.143 | 0.877 | 0.125 | 0.106 | **0.017** | **0.000** |
| Turb | 0.668 | **0.041** | 0 | **0.0001** | 0.960 | 0.258 | 0.569 | **0.019** | **0.001** | **0.007** |
| TSS | 0.896 | 0.119 | **0.0001** | 0 | 0.659 | 0.364 | 0.585 | **0.001** | **0.001** | **0.030** |
| DO Def. | 0.776 | 0.143 | 0.960 | 0.659 | 0 | 0.282 | 0.490 | 0.222 | 0.775 | **0.008** |
| BOD5b | 0.382 | 0.877 | 0.258 | 0.364 | 0.282 | 0 | 0.829 | **0.009** | **0.001** | **0.000** |
| NO3-N | 0.353 | 0.125 | 0.569 | 0.585 | 0.490 | 0.829 | 0 | 0.882 | 0.828 | 0.593 |
| PO4-P | 0.924 | 0.106 | **0.019** | **0.001** | 0.222 | **0.009** | 0.882 | 0 | **0.000** | 0.783 |
| FCB | 0.373 | **0.017** | **0.001** | **0.001** | 0.775 | **0.001** | 0.828 | **0.000** | 0 | 0.080 |
| WQI | 0.954 | **0.000** | **0.007** | **0.030** | **0.008** | **0.000** | 0.593 | 0.783 | 0.080 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 2. NARA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | -0.166 | -0.307 | 0.199 | -0.147 | -0.291 | -0.248 | 0.149 | 0.174 | **0.316** |
| pH | -0.166 | 1 | 0.236 | 0.090 | -0.048 | -0.127 | **0.337** | -0.227 | 0.219 | **0.478** |
| Turb | -0.307 | 0.236 | 1 | -0.277 | -0.278 | -0.038 | 0.047 | -0.100 | **0.398** | 0.239 |
| TSS | 0.199 | 0.090 | -0.277 | 1 | -0.121 | 0.061 | 0.140 | 0.134 | -0.004 | 0.065 |
| DO Def. | -0.147 | -0.048 | -0.278 | -0.121 | 1 | **0.578** | -0.129 | **-0.329** | **-0.421** | **0.468** |
| BOD5b | -0.291 | -0.127 | -0.038 | 0.061 | **0.578** | 1 | 0.046 | -0.266 | **-0.376** | **0.703** |
| NO3-N | -0.248 | **0.337** | 0.047 | 0.140 | -0.129 | 0.046 | 1 | 0.042 | -0.037 | 0.255 |
| PO4-P | 0.149 | -0.227 | -0.100 | 0.134 | **-0.329** | -0.266 | 0.042 | 1 | 0.199 | **0.353** |
| FCB | 0.174 | 0.219 | **0.398** | -0.004 | **-0.421** | **-0.376** | -0.037 | 0.199 | 1 | 0.034 |
| WQI | **0.316** | **0.478** | 0.239 | 0.065 | **0.468** | **0.703** | 0.255 | **0.353** | 0.034 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 2. NARA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.305 | 0.054 | 0.216 | 0.363 | 0.068 | 0.122 | 0.357 | 0.280 | **0.048** |
| pH | 0.305 | 0 | 0.143 | 0.578 | 0.768 | 0.434 | **0.034** | 0.159 | 0.174 | **0.002** |
| Turb | 0.054 | 0.143 | 0 | 0.084 | 0.082 | 0.817 | 0.775 | 0.537 | **0.011** | 0.137 |
| TSS | 0.216 | 0.578 | 0.084 | 0 | 0.456 | 0.705 | 0.387 | 0.408 | 0.983 | 0.689 |
| DO Def. | 0.363 | 0.768 | 0.082 | 0.456 | 0 | **0.000** | 0.425 | **0.039** | **0.007** | **0.003** |
| BOD5b | 0.068 | 0.434 | 0.817 | 0.705 | **0.000** | 0 | 0.779 | 0.097 | **0.017** | **0.0001** |
| NO3-N | 0.122 | **0.034** | 0.775 | 0.387 | 0.425 | 0.779 | 0 | 0.795 | 0.822 | 0.112 |
| PO4-P | 0.357 | 0.159 | 0.537 | 0.408 | **0.039** | 0.097 | 0.795 | 0 | 0.216 | **0.026** |
| FCB | 0.280 | 0.174 | **0.011** | 0.983 | **0.007** | **0.017** | 0.822 | 0.216 | 0 | 0.833 |
| WQI | **0.048** | **0.002** | 0.137 | 0.689 | **0.003** | **0.0001** | 0.112 | **0.026** | 0.833 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 3. LOWER MIMA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | 0.022 | 0.113 | -0.235 | 0.171 | -0.069 | -0.284 | 0.044 | 0.016 | 0.184 |
| pH | 0.022 | 1 | -0.281 | 0.081 | -0.109 | 0.021 | 0.069 | 0.116 | -0.106 | 0.291 |
| Turb | 0.113 | -0.281 | 1 | **-0.671** | 0.015 | -0.221 | 0.224 | **0.391** | **0.431** | 0.180 |
| TSS | -0.235 | 0.081 | **-0.671** | 1 | -0.074 | 0.159 | -0.011 | **-0.354** | **-0.568** | **0.389** |
| DO Def. | 0.171 | -0.109 | 0.015 | -0.074 | 1 | 0.095 | -0.168 | -0.124 | 0.126 | **0.439** |
| BOD5b | -0.069 | 0.021 | -0.221 | 0.159 | 0.095 | 1 | 0.010 | **-0.681** | **-0.563** | **0.532** |
| NO3-N | -0.284 | 0.069 | 0.224 | -0.011 | -0.168 | 0.010 | 1 | 0.107 | 0.046 | 0.029 |
| PO4-P | 0.044 | 0.116 | **0.391** | **-0.354** | -0.124 | **-0.681** | 0.107 | 1 | **0.639** | 0.037 |
| FCB | 0.016 | -0.106 | **0.431** | **-0.568** | 0.126 | **-0.563** | 0.046 | **0.639** | 1 | 0.100 |
| WQI | 0.184 | 0.291 | 0.180 | **0.389** | **0.439** | **0.532** | 0.029 | 0.037 | 0.100 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 3. LOWER MIMA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.892 | 0.487 | 0.144 | 0.291 | 0.671 | 0.076 | 0.787 | 0.922 | 0.254 |
| pH | 0.892 | 0 | 0.080 | 0.616 | 0.500 | 0.898 | 0.670 | 0.473 | 0.516 | 0.069 |
| Turb | 0.487 | 0.080 | 0 | **0.0001** | 0.929 | 0.170 | 0.164 | **0.013** | **0.006** | 0.266 |
| TSS | 0.144 | 0.616 | **0.0001** | 0 | 0.650 | 0.326 | 0.947 | **0.026** | **0.000** | **0.014** |
| DO Def. | 0.291 | 0.500 | 0.929 | 0.650 | 0 | 0.557 | 0.299 | 0.445 | 0.438 | **0.005** |
| BOD5b | 0.671 | 0.898 | 0.170 | 0.326 | 0.557 | 0 | 0.952 | **0.0001** | **0.000** | **0.000** |
| NO3-N | 0.076 | 0.670 | 0.164 | 0.947 | 0.299 | 0.952 | 0 | 0.509 | 0.777 | 0.856 |
| PO4-P | 0.787 | 0.473 | **0.013** | **0.026** | 0.445 | **0.0001** | 0.509 | 0 | **0.0001** | 0.821 |
| FCB | 0.922 | 0.516 | **0.006** | **0.000** | 0.438 | **0.000** | 0.777 | **0.0001** | 0 | 0.538 |
| WQI | 0.254 | 0.069 | 0.266 | **0.014** | **0.005** | **0.000** | 0.856 | 0.821 | 0.538 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 4. HIROMI

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 1 | 0.226 | -0.127 | -0.052 | -0.059 | 0.117 | | 0.180 | -0.016 | 0.162 |
| pH | 0.226 | 1 | **-0.341** | 0.014 | 0.040 | 0.040 | | 0.009 | -0.004 | **0.512** |
| Turb | -0.127 | **-0.341** | 1 | **-0.493** | 0.054 | -0.283 | | 0.239 | **0.387** | 0.044 |
| TSS | -0.052 | 0.014 | **-0.493** | 1 | -0.006 | 0.082 | | -0.271 | -0.220 | 0.172 |
| DO Def. | -0.059 | 0.040 | 0.054 | -0.006 | 1 | 0.094 | | 0.011 | 0.222 | **0.524** |
| BOD5b | 0.117 | 0.040 | -0.283 | 0.082 | 0.094 | 1 | | **-0.468** | **-0.501** | **0.542** |
| NO3-N | | | | | | | | | | |
| PO4-P | 0.180 | 0.009 | 0.239 | -0.271 | 0.011 | **-0.468** | | 1 | **0.608** | 0.027 |
| FCB | -0.016 | -0.004 | **0.387** | -0.220 | 0.222 | **-0.501** | | **0.608** | 1 | 0.152 |
| WQI | 0.162 | **0.512** | 0.044 | 0.172 | **0.524** | **0.542** | | 0.027 | 0.152 | 1 |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 4. HIROMI

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | 0 | 0.160 | 0.434 | 0.747 | 0.715 | 0.470 | | 0.265 | 0.920 | 0.315 |
| pH | 0.160 | 0 | **0.032** | 0.931 | 0.806 | 0.805 | | 0.955 | 0.981 | **0.001** |
| Turb | 0.434 | **0.032** | 0 | **0.001** | 0.737 | 0.077 | | 0.137 | **0.014** | 0.788 |
| TSS | 0.747 | 0.931 | **0.001** | 0 | 0.973 | 0.614 | | 0.091 | 0.173 | 0.288 |
| DO Def. | 0.715 | 0.806 | 0.737 | 0.973 | 0 | 0.564 | | 0.944 | 0.169 | **0.001** |
| BOD5b | 0.470 | 0.805 | 0.077 | 0.614 | 0.564 | 0 | | **0.003** | **0.001** | **0.000** |
| NO3-N | | | | | | | | | | |
| PO4-P | 0.265 | 0.955 | 0.137 | 0.091 | 0.944 | **0.003** | | 0 | **0.0001** | 0.867 |
| FCB | 0.920 | 0.981 | **0.014** | 0.173 | 0.169 | **0.001** | | **< 0.0001** | 0 | 0.349 |
| WQI | 0.315 | **0.001** | 0.788 | 0.288 | **0.001** | **0.000** | | 0.867 | 0.349 | 0 |

*Values in bold are different from 0 with a significance level alpha=0.05*

Appendix 16: Correlation analysis results using parameter index values for Mima, Nara, Lower Mima and Hiromi

Correlation matrix (Spearman): 5. HIROMI-MIMA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | -0.047 | 0.256 | -0.269 | -0.011 | -0.085 | 0.074 | 0.127 | -0.108 | 0.074 |
| pH | -0.047 | **1** | 0.101 | -0.086 | 0.047 | 0.121 | -0.105 | 0.093 | 0.185 | **0.430** |
| Turb | 0.256 | 0.101 | **1** | **-0.734** | -0.289 | -0.253 | **0.382** | **0.357** | **0.468** | 0.076 |
| TSS | -0.269 | -0.086 | **-0.734** | **1** | 0.255 | 0.206 | -0.222 | **-0.403** | **-0.531** | 0.143 |
| DO Def. | -0.011 | 0.047 | -0.289 | 0.255 | **1** | **0.487** | -0.011 | **-0.419** | **-0.405** | **0.568** |
| BOD5b | -0.085 | 0.121 | -0.253 | 0.206 | **0.487** | **1** | -0.022 | **-0.335** | **-0.582** | **0.756** |
| NO3-N | 0.074 | -0.105 | **0.382** | -0.222 | -0.011 | -0.022 | **1** | 0.205 | 0.156 | 0.144 |
| PO4-P | 0.127 | 0.093 | **0.357** | **-0.403** | **-0.419** | **-0.335** | 0.205 | **1** | **0.580** | 0.129 |
| FCB | -0.108 | 0.185 | **0.468** | **-0.531** | **-0.405** | **-0.582** | 0.156 | **0.580** | **1** | 0.106 |
| WQI | 0.074 | **0.430** | 0.076 | 0.143 | **0.568** | **0.756** | 0.144 | 0.129 | 0.106 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 5. HIROMI-MIMA

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.772 | 0.110 | 0.094 | 0.948 | 0.599 | 0.647 | 0.432 | 0.506 | 0.647 |
| pH | 0.772 | **0** | 0.535 | 0.596 | 0.773 | 0.456 | 0.516 | 0.568 | 0.252 | **0.006** |
| Turb | 0.110 | 0.535 | **0** | **0.0001** | 0.070 | 0.115 | **0.016** | **0.024** | **0.003** | 0.640 |
| TSS | 0.094 | 0.596 | **0.0001** | **0** | 0.112 | 0.202 | 0.169 | **0.010** | **0.001** | 0.377 |
| DO Def. | 0.948 | 0.773 | 0.070 | 0.112 | **0** | **0.002** | 0.947 | **0.008** | **0.010** | **0.000** |
| BOD5b | 0.599 | 0.456 | 0.115 | 0.202 | **0.002** | **0** | 0.894 | **0.035** | **0.000** | **0.0001** |
| NO3-N | 0.647 | 0.516 | **0.016** | 0.169 | 0.947 | 0.894 | **0** | 0.203 | 0.335 | 0.372 |
| PO4-P | 0.432 | 0.568 | **0.024** | **0.010** | **0.008** | **0.035** | 0.203 | **0** | **0.000** | 0.428 |
| FCB | 0.506 | 0.252 | **0.003** | **0.001** | **0.010** | **0.000** | 0.335 | **0.000** | **0** | 0.513 |
| WQI | 0.647 | **0.006** | 0.640 | 0.377 | **0.000** | **0.0001** | 0.372 | 0.428 | 0.513 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 6. LOWER HIROMI

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | **0.378** | **0.320** | -0.155 | 0.298 | -0.183 | | 0.122 | 0.213 | 0.297 |
| pH | **0.378** | **1** | -0.218 | 0.051 | 0.188 | 0.050 | | 0.170 | 0.011 | **0.587** |
| Turb | **0.320** | -0.218 | **1** | **-0.518** | -0.036 | **-0.319** | | **0.327** | **0.584** | 0.064 |
| TSS | -0.155 | 0.051 | **-0.518** | **1** | 0.114 | 0.077 | | -0.242 | **-0.413** | 0.150 |
| DO Def. | 0.298 | 0.188 | -0.036 | 0.114 | **1** | 0.004 | | -0.067 | 0.048 | **0.502** |
| BOD5b | -0.183 | 0.050 | **-0.319** | 0.077 | 0.004 | **1** | | **-0.455** | **-0.471** | **0.481** |
| NO3-N | | | | | | | | | | |
| PO4-P | 0.122 | 0.170 | **0.327** | -0.242 | -0.067 | **-0.455** | | **1** | **0.653** | 0.013 |
| FCB | 0.213 | 0.011 | **0.584** | **-0.413** | 0.048 | **-0.471** | | **0.653** | **1** | 0.043 |
| WQI | 0.297 | **0.587** | 0.064 | 0.150 | **0.502** | **0.481** | | 0.013 | 0.043 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 6. LOWER HIROMI

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | **0.017** | **0.045** | 0.337 | 0.062 | 0.258 | | 0.451 | 0.187 | 0.063 |
| pH | **0.017** | **0** | 0.176 | 0.751 | 0.245 | 0.758 | | 0.293 | 0.947 | **0.0001** |
| Turb | **0.045** | 0.176 | **0** | **0.001** | 0.824 | **0.045** | | **0.040** | **0.000** | 0.693 |
| TSS | 0.337 | 0.751 | **0.001** | **0** | 0.482 | 0.636 | | 0.132 | **0.008** | 0.353 |
| DO Def. | 0.062 | 0.245 | 0.824 | 0.482 | **0** | 0.982 | | 0.680 | 0.765 | **0.001** |
| BOD5b | 0.258 | 0.758 | **0.045** | 0.636 | 0.982 | **0** | | **0.004** | **0.002** | **0.002** |
| NO3-N | | | | | | | | | | |
| PO4-P | 0.451 | 0.293 | **0.040** | 0.132 | 0.680 | **0.004** | | **0** | **0.0001** | 0.935 |
| FCB | 0.187 | 0.947 | **0.000** | **0.008** | 0.765 | **0.002** | | **< 0.0001** | **0** | 0.792 |
| WQI | 0.063 | **0.0001** | 0.693 | 0.353 | **0.001** | **0.002** | | 0.935 | 0.792 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 7. UPPER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | 0.006 | -0.148 | 0.147 | 0.051 | -0.176 | | -0.096 | 0.053 | 0.181 |
| pH | 0.006 | **1** | -0.173 | -0.105 | -0.205 | -0.020 | | 0.150 | 0.094 | 0.204 |
| Turb | -0.148 | -0.173 | **1** | -0.284 | -0.126 | **-0.332** | | 0.259 | **0.557** | 0.019 |
| TSS | 0.147 | -0.105 | -0.284 | **1** | 0.231 | 0.167 | | 0.046 | -0.177 | 0.035 |
| DO Def. | 0.051 | -0.205 | -0.126 | 0.231 | **1** | **0.329** | | -0.042 | -0.144 | **0.537** |
| BOD5b | -0.176 | -0.020 | **-0.332** | 0.167 | **0.329** | **1** | | -0.119 | **-0.523** | **0.750** |
| NO3-N | | | | | | | | | | |
| PO4-P | -0.096 | 0.150 | 0.259 | 0.046 | -0.042 | -0.119 | | **1** | 0.244 | 0.103 |
| FCB | 0.053 | 0.094 | **0.557** | -0.177 | -0.144 | **-0.523** | | 0.244 | **1** | 0.071 |
| WQI | 0.181 | 0.204 | 0.019 | 0.035 | **0.537** | **0.750** | | 0.103 | 0.071 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 7. UPPER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.972 | 0.361 | 0.363 | 0.755 | 0.277 | | 0.553 | 0.746 | 0.264 |
| pH | 0.972 | **0** | 0.284 | 0.517 | 0.205 | 0.900 | | 0.355 | 0.561 | 0.206 |
| Turb | 0.361 | 0.284 | **0** | 0.076 | 0.438 | **0.037** | | 0.106 | **0.000** | 0.905 |
| TSS | 0.363 | 0.517 | 0.076 | **0** | 0.150 | 0.303 | | 0.779 | 0.273 | 0.831 |
| DO Def. | 0.755 | 0.205 | 0.438 | 0.150 | **0** | **0.039** | | 0.799 | 0.375 | **0.000** |
| BOD5b | 0.277 | 0.900 | **0.037** | 0.303 | **0.039** | **0** | | 0.462 | **0.001** | **0.0001** |
| NO3-N | | | | | | | | | | |
| PO4-P | 0.553 | 0.355 | 0.106 | 0.779 | 0.799 | 0.462 | | **0** | 0.129 | 0.526 |
| FCB | 0.746 | 0.561 | **0.000** | 0.273 | 0.375 | **0.001** | | 0.129 | **0** | 0.664 |
| WQI | 0.264 | 0.206 | 0.905 | 0.831 | **0.000** | **0.0001** | | 0.526 | 0.664 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Correlation matrix (Spearman): 8. LOWER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **1** | 0.265 | 0.079 | -0.123 | -0.074 | -0.127 | | 0.135 | 0.095 | 0.127 |
| pH | 0.265 | **1** | -0.191 | 0.252 | -0.183 | -0.163 | | 0.146 | 0.210 | 0.123 |
| Turb | 0.079 | -0.191 | **1** | **-0.336** | -0.091 | **-0.411** | | 0.217 | **0.617** | 0.054 |
| TSS | -0.123 | 0.252 | **-0.336** | **1** | -0.077 | -0.071 | | -0.144 | -0.240 | 0.203 |
| DO Def. | -0.074 | -0.183 | -0.091 | -0.077 | **1** | 0.266 | | -0.240 | -0.121 | **0.568** |
| BOD5b | -0.127 | -0.163 | **-0.411** | -0.071 | 0.266 | **1** | | **-0.348** | **-0.562** | **0.643** |
| NO3-N | | | | | | | | | | |
| PO4-P | 0.135 | 0.146 | 0.217 | -0.144 | -0.240 | **-0.348** | | **1** | **0.320** | 0.075 |
| FCB | 0.095 | 0.210 | **0.617** | -0.240 | -0.121 | **-0.562** | | **0.320** | **1** | 0.019 |
| WQI | 0.127 | 0.123 | 0.054 | 0.203 | **0.568** | **0.643** | | 0.075 | 0.019 | **1** |

*Values in bold are different from 0 with a significance level alpha=0.05*

p-values: 8. LOWER SHIMANTO

| Variables | ΔT | pH | Turb | TSS | DOb | BOD5b | NO3-N | PO4-P | FCB | WQI |
|---|---|---|---|---|---|---|---|---|---|---|
| ΔT | **0** | 0.099 | 0.625 | 0.448 | 0.649 | 0.435 | | 0.404 | 0.557 | 0.435 |
| pH | 0.099 | **0** | 0.237 | 0.117 | 0.257 | 0.314 | | 0.366 | 0.193 | 0.448 |
| Turb | 0.625 | 0.237 | **0** | **0.035** | 0.575 | **0.009** | | 0.177 | **0.0001** | 0.740 |
| TSS | 0.448 | 0.117 | **0.035** | **0** | 0.637 | 0.662 | | 0.373 | 0.135 | 0.207 |
| DO Def. | 0.649 | 0.257 | 0.575 | 0.637 | **0** | 0.097 | | 0.135 | 0.456 | **0.000** |
| BOD5b | 0.435 | 0.314 | **0.009** | 0.662 | 0.097 | **0** | | **0.028** | **0.000** | **0.0001** |
| NO3-N | | | | | | | | | | |
| PO4-P | 0.404 | 0.366 | 0.177 | 0.373 | 0.135 | **0.028** | | **0** | **0.044** | 0.644 |
| FCB | 0.557 | 0.193 | **0.0001** | 0.135 | 0.456 | **0.000** | | **0.044** | **0** | 0.906 |
| WQI | 0.435 | 0.448 | 0.740 | 0.207 | **0.000** | **0.0001** | | 0.644 | 0.906 | **0** |

*Values in bold are different from 0 with a significance level alpha=0.05*

Appendix 17: Correlation analysis results using parameter index values for Hiromi-Mima confluence, Lower Hiromi, Upper Shimanto and Lower Shimanto